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UNIVERSITY OF ALBERTA

THE EFFECTS OF DIFFERENT CROPPING SYSTEMS ON A LUVISOLIC SOIL IN THE PEACE RIVER REGION

BY

KLAAS BROERSMA

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY

IN

SOIL FERTILITY

DEPARTMENT OF SOIL SCIENCE

EDMONTON, ALBERTA

(SPRING, 1991)

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ISBN 0-315-66772-9

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DEDICATION

To Jenny my wife,

and our children,

Keith,

Garrett,

and

Conrad

ABSTRACT

Luvisolic soils are difficult to manage agriculturally because adverse inherent characteristics in the A and B horizon and in addition are generally located in areas with inferior climate. In this study the effects of diverse cropping systems, from a long-term cropping system experiment established in 1968 on a Luvisolic soil in the Peace River Region of Alberta, and consisting of: 1)continuous barley (CB), 2a)barley/forage (Bf), 2b)forage/barley (Fb), 3)continuous grass (CG) and 4)continuous legume (CL) were evaluated. The overall objectives i)were to summarize 20 years of management data, ii)to determine soil water property changes, iii)to determine aggregate distribution and stability, iv)to estimate net nitrogen potentials (N_0), and v) to determine net nitrogen (N) mineralization when amended with plant residues.

The inclusion of forage crops in the cropping systems resulted in changes in soil properties. Levels of organic matter in the CG and CL cropping systems are higher. The bulk density of the surface horizon for the CL cropping system was lower while the modulus of rupture for the CB system was greater than the other cropping systems. Forage crops improved soil water properties with increased saturated hydraulic conductivity of the 15-30 cm in the CG cropping system and 15-30 and 30-45 cm depth intervals for the CL cropping system. Higher rates of infiltration of the CG and CL cropping systems were also observed.

Aggregate distributions by wet and dry sieving were different. Aggregate stability determined by wet sieving, the McCala waterdrop method and the dispersion/slaking index all showed that aggregate stabilities decreased for the cropping systems in the order of: $CG > CL > Bf \geq Fb \geq CB$.

Inclusion of forage crops resulted in an increase in the amount of organic matter and N_0 (potential mineralizable N pool). The CL cropping system had the higher mineralization rates and a greater N_0 compared to the other cropping systems. Initial mineralization rates at time=0 could not be used to predict N_0.

The accumulation of N from surface soils amended with plant residue amendments was dependent on the cropping system and amendment. The addition of fababean plant residue to the cropping system soils generally resulted in net N mineralization while the addition of fescue or barley resulted in net N immobilization. Contribution of the plant residue amendments to the accumulated N over 20 weeks amounted to proportions of 7.1, 10.5 and 14.0 % for the fescue, barley and fababean amendments, repectively, across all cropping systems.

ACKNOWLEDGEMENTS

Thanks first and foremost goes to my family, Jenny and our boys Keith, Garrett and Conrad, for putting up with a part-time husband and father during the course of this graduate program.

Sincere appreciation and thanks are expressed to Dr. J.A. Robertson for being my supervisor at the University of Alberta and for guidance, encouragement, discussions and constructive criticism during the course of this study and for the assistance in the preparation and reviewing of the thesis.

I would also like to thank Agriculture Canada for allowing me to go back to university to obtain my doctorate degree. Appreciation is expressed to Mr.W.L.(Bill) Pringle, former superintendent of the Prince George Experimental Farm, who convinced me to take the final steps towards this graduate program when I was in doubt about going through with it. He also made me aware of the Beaverlodge Long-term Cropping System Field Experiment. Gratefulness is expressed to Dr. J.A.(Alden) Robertson, director of the Agriculture Canada, Kamloops Research Station for his support and time to work on the research project. The author is grateful for financial assistance from Agriculture Canada and from the Agricultural Research Council of Alberta (Farming for the Future Program).

A special thanks is warranted for my staff at the Prince George Experimental Farm. Mrs. Ann Robertson was always there to "word process" parts of the manuscript with those complicated tables and picking up some of my responsibilities in the office and thereby making it easier for myself. In the laboratory and with computer analyses I received help and advise from Arthur Yee, Sheila Carey, Patricia Kline and Dave Pickering. My other employees Bryan Warner, William Tavenier, Royce Dahmer and Ken Carson did their work with minimum supervision so that I didn't have to be too concerned with the every day operation of the Prince George Experimental Farm at all times.

Gratitute is also expressed to the remainder of my committee, Drs. N.G. Juma and D.S. Chanasyk from the University of Alberta and Dr. V.S. Baron from the Agriculture Canada, Research Station at Lacombe for serving on the research committee, directing the project and reviewing

and editing the thesis. Dr. N.G. Juma spend considerable time with on the N mineralization work. Appreciation is also expressed to Dr. A.L. van Ryswyk who helped with the editing of chapters 2 to 4.

Special thanks to Drs. W.B. McGill and S.P.Wani for reviewing and recommending improvements to Chapters 5 and 6.

I also wish to thank Mr. Clive Figueiredo for ^{15}N analyses and Mr. John Konwicki for N analyses of my soil samples at the University of Alberta.

As my research site was located at the Beaverlodge Research Station I would like to thank the staff for helping me with equipment and data from the Beaverlodge Long-term Cropping System Field Experiment. Special thanks are expressed to Mr. A.M.F. Hennig, Mr. Larry Kerr and Dr. Young Soon for their help at the Beaverlodge site.

Working in Prince George and doing graduate work at the University of Alberta resulted in me being away from home fairly often. My home away from home in Edmonton was at the Smit's residence were I was always welcome. Thank you Harma for being there with your hospitality when ever I was at the university.

I am sorry if I have forgotten someone that should have special mention as over the years of study one comes in contact with many people. One thing that was learned from this graduate program is that it required many people working together to produce the final project and that these include family, friends and colleagues.

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CHAPTER 1

Luvisolic Soils in Agriculture.

1.1 INTRODUCTION

Luvisolic soils in Canada are found coast to coast and from southern Ontario to the permafrost zone in northern Canada. These soils have developed under a forest vegetation. Gray Luvisols occur in the cooler Boreal, Cryoboreal and Sub-arctic regions (Clayton et al. 1977) but are concentrated in the northern interior plains of the "Prairie Provinces". The largest block of Gray Luvisols is found in Alberta which has some 20 million hectares of which close to 30 % is considered arable (Holmes et al. 1976). A significant portion, 15 percent, of all the present cultivated area in Alberta have Gray Luvisolic soils. Present and future expansion of arable agriculture will be dominantly onto this soil.

Gray Luvisolic soils possess several profile characteristics which can lead to management problems for producers. The surface mineral horizon (Ae), which becomes part of the "plow layer" upon farming, is low in organic matter, clay, and several nutrients including nitrogen (N), phosphorus (P) and sulfur (S). It also is slightly to moderately acidic and has poor tilth when cultivated. The lower (Bt) horizon in which clay has accumulated is quite firm and compact thus restricting water percolation and root penetration. This lower horizon is usually moderately acidic. Many of these characteristics can be changed in response to man's activities of growing crops, cultivation, fertilization and liming.

Continued viable agricultural use of the Gray Luvisolic soils requires knowledge about the impact of various management practices on soil properties. Management practices which enhance the productivity and quality of these soils need to be identified and studied. In this chapter some of the literature pertaining to the physical, chemical and biological properties of Luvisolic soils and the effects of management on these properties is reviewed.

1.2 LITERATURE REVIEW

1.2.1 Distribution and Characteristics of Luvisols in Canada

Luvisolic soils are found throughout Canada. They occur from the southern extremity of Ontario at a latitude of approximately 43° N to the zone of permafrost in the north. In an east to west direction, Luvisolic soils can be found from Newfoundland to British Columbia. The largest concentration of these soils occurs in the Central to Northern Interior Plains (Prairies) under deciduous, mixed and coniferous forest cover. The largest block of Luvisolic soils is found in the province of Alberta which has aproximately 20 million hectares, of which nearly 30 % is considered to be arable (Holmes et al. 1976). In Alberta cultivated Gray Luvisols constitute approximately 15 % of the present cultivated area (Bentley et al. 1971) and any future expansion of agriculture will be mainly in areas dominated by these soils.

Luvisolic soils according to "the Canadian System of Soil Classification" (Agriculture Canada Expert Committee on Soil Survey 1987) have light-colored, eluvial horizons (Ae) and illuvial B horizons in which silicate clay has accumulated (Bt). These soils develop characteristically in well to imperfectly drained sites, in sandy loam to clay-textured, base-saturated parent materials under forest vegetation in subhumid to humid, mild to very cold climates. Luvisolic soils also occur outside the characteristic areas. Luvisolic soils are quite common also in the pH neutral parent materials of the forest-grassland transition zones and also develop in acidic parent materials. In the Central to Northern Interior Plains, Gray Luvisols have: well-developed, platy Ae horizons of low chroma, Bt horizons with moderate to strong prismatic or blocky structures, and calcareous parent material and sola of relatively high base saturation. In eastern Canada these soils commonly have much weaker structured Bt horizons and lower base saturation. In southern Ontario and some areas of British Columbia, soils from this order have a forest mull (Oh) horizon, moderate to strong blocky-structured Bt horizons, calcareous parent material and are classified as Gray Brown Luvisols.

According to The Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey 1987) Luvisolic soils must have an Ae (eluvial) and Bt (illuvial) horizon. The Bt horizon must be at least 5 cm thick, have a specified increase in clay over that in the Ae horizon, and clay skins must be present. The clay skins are indicative of translocated clay and should account for 1 % or more of the area of a cross-section through the Bt horizon. Luvisolic soils may have Ah, Ahe or dark-colored Ap horizons that satisfy one or more of the following conditions:

1. The dark-colored A horizon does not meet the requirement of a Chernozemic A.
2. The dark-colored A horizon is underlain by a thicker, light colored Ae horizon that extends to a depth 15 cm from the mineral surface.
3. The dark-colored A horizon shows evidence of eluviation (Ahe or Ap) and is underlain by an Ae horizon at least 5 cm thick.
4. If the soil moisture subclass is humid or wetter, the dark-colored A horizon may be of any kind.

1.2.2 Problems with Luvisolic Soils

The importance of Luvisolic soils is increasing as more of these soils are being brought into agricultural production. Potentially 40 % of all cultivated land in Alberta could be Luvisolic (Bentley et al. 1971). Sustainable farming of these soils is dependent on improvement and maintenance of soil fertility and the soil physical properties. Bentley et al. (1971) stated that on agriculturally good soils such as Chernozems, even with poor farming methods, respectable crops can be produced whereas "good farming methods must be followed to obtain satisfactory crop yields" on agriculturally poor soils such as Luvisolic soils.

Problems in the management of Luvisolic soils have been recognized for many years (Newton 1952, McFall 1959, Nuttall 1972, Lavkulich 1980, Robertson and McGill 1983). Newton (1952) mainly stressed the soil's fertility problems. Bentley (summarized by McFall, 1959) noted that Luvisolic soils have poor physical and chemical properties primarily because of lack of humus. Nuttall (1972) studied the effect of physical properties of these soils for the establishment and growth of agricultural crops compared to Chernozemic soils. Most of the soil-related management problems of Luvisolic soils result from the low organic matter levels of the A horizon and the undesirable properties of the B horizon. This was summarized schematically by Robertson and McGill (1983) (Table 1.1).

Easily manageable soils differ from problem soils in physical, chemical or biological characteristics or in a combination of these qualities. A soil with desirable physical, chemical, and biological properties generally has an adequate amount of organic matter and good

Table 1.1 Soil-related management problems on Luvisolic soils (adapted from Robertson and McGill 1983)

A Horizon Low organic matter weak structure acidic	-Crusting	-Restricted seedling emergence -Reduced aeration -Impeded infiltration -Erosion -Reduced water reserve
	-Tillage problems	-Pulverization -Clodding -Compaction
	-Low water holding capacity	-Poor germination, emergence -More exacting seed-bed preparation
	-Low fertility	-Nitrogen -Phosphorus -Sulfur
	-Low buffering against pH change	-More rapid acidification -More frequent liming
B Horizon dense, very firm, acidic	-Impeded water transmission	-Puddling of A horizon -Tillage delays -Denitrification -Erosion -Reduced water reserve
	-Restricted root growth	-Reduced water supply -Reduced nutrient pool -Reduced recycling of calcium from C horizon

tilth. The organic matter contents of Luvisols are much lower than those of Chernozems (Bentley et al. 1971, McGill 1983) and the tilth is also much poorer (McFall 1959, Nuttall 1972).

1.2.3 Climate

Temperature and moisture the most fundamental limiting factors to crop production on the Canadian Prairies. Temperature controls the range of crops that can be grown in a region while moisture determines the ultimate yield. Climate, therefore, has a strong influence on the plant species that can be grown, the quantity of plant material that is produced and the microbial activity of the soil.

The suitability of an area for various crops is related to the frost-free period. In Alberta, less than 20 % of the total land area has a frost-free period of 100 days or more and 50 % or more of the area has a frost-free period of less than 80 days (Peters and Pettapiece 1981).

Crops best suited to Alberta conditions have a growing period between 70 and 120 days. Canola (Brassica campestris and Brassica napus) require 75-83 and 105-115 days to mature, respectively. Field beans require 105-115 days to mature but are much more sensitive to low temperatures and frost at all stages of growth. Cereals (oats, barley and wheat) require 85-95, 85-90 and 90-100 days to mature, respectively. In relation to crop production, Luvisolic soils are associated with a shorter growing season or frost-free period and therefore only a limited number of crops can be grown successfully.

Heat units and degree days are indices of temperature above some minimum (usually 5 or 5.6°C) summed over the year or growing season. Degree days in Alberta range from 1600-1800 in the south-east to 800 or less in the foothills west of Red Deer. In the Peace River region, degree days total about 1000-1100, because of influence of lower elevation and longer summer daylight hours. Luvisolic soils are generally associated with areas having lower heat units or degree days.

Water use efficiency by crops is defined as the amount of dry matter produced per unit of water used (Viets 1962) and has been shown to increase with fertility (Tisdale et al. 1985) and as water becomes more limiting (de Jong and Cameron 1980). Crops grown on Luvisolic soils have a lower water use efficiency than those on Chernozemic soils (de Jong and Cameron 1980) because water is less limiting on Luvisolic soils. Fertilizer or manure increased water use efficiency on Gray Luvisols when used separately, but when applied together no complementary benefit was found (Hoyt and Rice 1977).

Wet soil conditions in the spring or fall can delay seeding or harvesting in an already short growing season on the Luvisolic soils. Increasing soil water can also decrease soil temperature in the spring. Problems for farming operations arise from the ponding of excess water, which results in poor trafficability for machinery and poor growth conditions for the crop (Chanasyk et al. 1983).

1.2.4 Physical Characteristics

1.2.4.1 Soil Degradation

The Science Council of Canada (1986) listed types of degradation that are prevalent in agriculture as: erosion by wind and water, salinization, acidification, compaction, and loss of organic matter. The problems of soil degradation have been brought to the foreground by symposia (Harapiak 1981), government reports (Sparrow 1984, Science Council of Canada 1986) and researchers (Rennie 1979a, Rennie 1979b, Campbell and Biederbeck 1980, Coote 1980, Coote et al. 1981, McGill 1982). Although generally the inherent soil productivity of agricultural soils has decreased due to soil degradation, yields have increased or been maintained due to technological advances including weed control, fertilization, better machinery and better varieties that have compensated for losses in soil productivity (Cameron et al. 1981). For Luvisolic soils, the loss of organic matter, water erosion, acidification and compaction are the dominant forms of degradation.

1.2.4.2 Loss of Soil Organic Matter

Gray Luvisolic soils generally contain less than half as much organic matter as do any of the Chernozemic soils (McGill et al. 1981). Even though the Black Chernozemic soils have lost large quantities of organic matter, they still contain more than the Gray Luvisolic, Brown Chernozemic and some Dark Brown Chernozemic soils prior to cultivation. The smallest proportional loss of organic matter on cultivation according to McGill et al. (1981) appears to be in the Gray Luvisolic soils, even though these soils have the highest decomposition rate and the smallest amount initially. The lower proportional loss of organic matter in Luvisolic soils can be attributed to a higher ratio of carbon (C) added annually to initial C present by forage crops and to a shorter history of cultivation.

Cultural practices and cropping systems have been shown to affect the levels of organic matter in soils (Newton et al. 1945, Hill 1954, Campbell et al. 1976, McGill and Hoyt 1977, Campbell and Biederbeck 1980, Reinl 1984). Agricultural activities have lowered organic matter levels because organic matter inputs are generally less than amounts decomposed. Soil erosion and practices that include annual tillage such as for annual cropping and summer-fallowing have accelerated organic matter loss (Rovira and Graecen 1957).

1.2.4.3 Aggregate Stability

Aggregate stability is an important soil characteristic of soil structure. Soil structure has been defined as "the manner in which soil particles are assembled in aggregate form" (Hausenbuiller 1972). Breakdown of soil aggregates into smaller aggregates and primary particles can lead to erosion, sealing of the soil surface, and crusting. These are all problems regularly experienced when managing Luvisolic soils.

Soil erodibility is a function of soil physical properties and soil management (Hudson 1981). Stability of the aggregates is important to erosion prevention. Soil aggregate stability has been found to increase with increasing clay content (Middleton 1930, Kemper and Koch 1966, Wustamidim and Douglas 1985). Surface horizons of Luvisolic soils are low in clay (Pawluk 1960 and 1961) because of clay eluviation and therefore these horizons have poor aggregate stability. Kemper and Koch (1966) found the relationship between aggregate stability and clay to be hyperbolic, so that a small increase in clay increases aggregate stability significantly.

Decomposition of added residues can lead to increased aggregation (Harris et al. 1966). Since decomposition is an ongoing process the chemical composition of residue, the amounts and the factors influencing the decomposition, such as tillage, are very important in determining soil structure. The positive effects of cropping systems and crop types with reduced tillage on soil aggregation have been well studied (Harris et al. 1966, Lynch and Bragg 1985, Burns and Davies 1986). Toogood and

Lynch (1959) showed that Luvisolic soils under a 5-year rotation of grains (3 years) and forages (2 years) had almost double the mean weight diameter of aggregates compared to soils in a wheat-fallow sequence.

Organisms mediate aggregation in two ways: they can either mechanically bind particles of soil together or they produce binding agents through the synthesis or decomposition of organic materials (Lynch and Bragg 1985). Inclusion of forage crops in a cropping system increases aggregation. In concert with forage production tillage, which reduces aggregation, is eliminated (Harris et al. 1966).

1.2.4.4 Water Erosion and Infiltration

Destruction of plant cover through tillage makes soil more susceptible to erosion. Three land parameters that control wind erosion, according to Chepil (1954), are roughness, cover and obstructions. The breakdown of soil aggregates and detachment of soil particles through the impact of rain-drops and the downhill transport of these materials results in water erosion (Rosewell and Marstan 1978). Luvisolic soils are especially susceptible to wind and water erosion because of their weak surface structure and low amounts of organic matter.

Crops, crop residues and/or humus in the soil surface help to absorb the impact of raindrops, thereby protecting the soil from disaggregation, decreasing surface sealing and crusting, and improving infiltration (Marstan and Doyle 1978). Increasing the ground cover from 20 to 60 % reduced the average annual runoff from 175 to 30 mm (Lang 1979). Toogood (1963) showed that a silt loam with a 12 % slope near Edmonton had soil losses of 0.007, 0.94 and 2.0 t ha^{-1} annually from virgin sod, stubble and fallow, respectively, over a 10 year period

(1950-60). In Ontario Webber (1964) reported annual soil losses from a Guelph loam with a 7 % slope and cropped to continuous corn to be 17 t ha^{-1} compared to negligible losses from continuous forage plots. In the Peace River region of Alberta, soil erosion by snowmelt runoff from agricultural land was shown to be the greatest from fallow and the least from fescue plots while barley and canola with stubble remaining were intermediate (Chanasyk and Woytowich 1987). Fenster et al. (1977) cited the work of Barnes and Bohment (1958) from Wyoming that showed water infiltration rates increased with forage and stubble: 0.8 to 3.0 and 5.7 cm h^{-1} for fallow, grassland and stubble, respectively. Deep rooted crops such as alfalfa also increase infiltration (Mazaruk et al. 1955).

1.2.5 Soil Chemical Properties

Soil fertility is defined as the status of the soil in relation to the amount and availablity to plants of elements necessary for plant production (Canada Department of Agriculture 1972). Soil fertility is affected by organic matter, mineralogy, acidity, salinity, crusting, tilth, structure of the subsoil, etc. (McGill 1982). Luvisolic soils are difficult to manage because many of the factors that make the soil fertile are lacking in them (Table 1.1).

1.2.5.1 Organic Matter

Organic matter is important for two reasons: first, it serves as a revolving nutrient pool and secondly, as an agent to improve or maintain soil structure and tilth. Erosion is reduced because of increased infiltration and aeration. Organic matter also supplies ion exchange sites and is a source of physiologically active substances in addition to the above reasons (McGill and Hoyt 1977). The low organic matter content of Luvisolic soils causes most of their management problems.

Average organic matter is below the critical level to maintain a Luvisolic soil in a stable condition (McGill 1982). The average organic matter content for Luvisolic soils at present is about 1.6 % while the critical level is considered to be about 2.7 % (McGill 1982).

Gray Luvisolic soils contain less organic matter than Chernozemic soils and it is also distributed differently (McGill 1982). In virgin Luvisolic soils, organic matter is mostly located on the surface of the mineral horizons while in the Chernozemic soils it is distributed throughout the surface mineral horizons as complexed organo-mineral material. Upon cultivation, the non-complexed and unstablized organic litter of Luvisolic soils decomposes rapidly and soil structural and nutrient deficiencies are quickly encountered. Therefore, proper management of organic reserves becomes critical on Luvisolic soils. The inclusion of forage crops in a cropping system (as part of rotation or plowdown) can increase the organic matter content of soils. Nonetheless, the introduction of a continuous grass crop on a Luvisolic soil for nearly fifty years did not induce mull-forming biological processess to compensate for the physico-chemical lessivage process characteristic of these soils (Martin et al. 1987).

1.2.5.2 Nutrient Supply

Wyatt and Ward (1929) reported that the amounts of the plant nutrient elements nitrogen, phosphorus, calcium and magnesium are lower in Gray Luvisolic than Black Chernozemic soils. They observed that the top 1 m of soil Chernozemic soils had four times as much nitrogen, twice as much phosphorus, twice as much calcium and more magnesium. The application of fertilizers to recently cleared Luvisolic soil resulted in average yield increases for barley, sweet clover, wheat, oats and red clover of 16 % for N, 29 % for lime, 47 % for manure, 53 % for P, 63 % for mixed fertilizer and 65 % for lime plus phosphorus (Wyatt and Ward 1929). Organic matter serves as the main source of N and S in prairie agricultural soils and accounts for about one-half of the P (McGill and Hoyt 1977). Because the levels of organic matter are low in Luvisolic soils, so are the plant nutrients N, P and S.

Research of Gray Luvisolic soils has indicated that these soils are deficient in N and S (Newton 1936, Robertson and McGill 1983). Applications of both nutrients are required for non-legumes while only S is required for properly inoculated legumes. Phosphorus has also been shown to be beneficial on Luvisolic soils (Robertson 1979). At present, K deficiencies have only been found occasionally, but based on current soil test results and field observations, K deficiencies will likely become more common as these soils are cropped longer and as other nutrients are increased with higher rates of fertilization (Robertson 1979). Other nutrients such as manganese and boron have also been shown to be deficient occasionally.

1.2.5.3 Acidity

Soils become acidic through the replacement of basic cations by the hydrogen ion (H^+). This occurs when crops are exported from the farm and by the generation of acids through biological oxidation. The biological oxidation of C to CO_2, nitrogen to NO_3-N and sulfur to SO_4-S all supply H^+ to the soil, displacing cations and decreasing soil pH. Augmented acidification by fertilizers is especially serious for Luvisolic soils as they are already acidic and have a low buffering capacity. Our awareness of acidic soils is increasing because many of the more recent areas developed for agriculture have acidic soils and intensive agriculture enhances the acidification process (Hoyt et al. 1981). The acidification of Luvisolic soils makes management of these soils even more difficult than at present as it affects soil structure (Hoyt 1981) and the production of crops (Elliot et al. 1973, Hoyt et al. 1974).

Fertilizer, particulary NH_4-N and S^o, is a major source of soil acidification in western Canada. Cairns (1971) reported that the pH of a Solonetzic soil was lowered from 5.8 to 4.7 in 10 years by the application of high rates of ammonium phosphate-sulfate (16-20-0) fertilizer. The application of 11 kg ha^{-1} of N and 9 kg ha^{-1} of S (as NH_4-N and SO_4-S), annually on a medium textured Gray Luvisol, at the Breton Plots, for over 40 years resulted in soil pH decreasing by 0.5 units to 5.3 (McCoy and Webster 1977). Similar trends were also demonstrated by Nyborg and Mahli (1981) on the same soil. On a Gray Luvisolic soil in the Peace River region, pH dropped 0.24 units following four consecutive applications of 16-20-0 at 112 kg ha^{-1} and increasing the N rate to 139 kg ha^{-1} of N decreased the pH by 0.43 units (Hoyt et al. 1981).

The extent of acidification is affected by agricultural management practices. Nyborg and Mahli (1981) reported that using nitrification inhibitors and banding nitrogen fertilizers lessened the pH drop. Crop production can also affect soil pH. Cereal and oilseed crops remove small amounts of bases from the soil compared to legume hay crops such as alfalfa (Hoyt et al. 1981). Fixation of atmospheric N by legumes can also acidify the soil (Nyatsanga and Pierre 1973). Cultivation and erosion also affect soil pH. In a Gray Luvisol, mixing of the subsoil which has a lower pH can reduce the pH of the surface horizon. Topsoil removal by erosion will leave behind the more acidic soil.

1.2.6 Soil Biological Characteristics

1.2.6.1 Biological Activity

Management of the soil (Jenkinson and Powlson 1976), tillage methods (Carter and Rennie 1982, Lynch and Panting 1980), and environmental conditions during the season (Clarholm and Rosswall 1980, Lynch and Panting 1980) all affect the biological activities of the soil. Aeration, moisture, temperature, food sources and soil pH must all be adequate if the "proper" competing organisms are to be present (Sopher and Baird 1978). As was shown previously, many of these conditions are not very favourable in a Luvisolic soil.

1.2.6.2 Faunal Activity

Dominant agricultural practices (tillage, fallow cultivation, monoculture, pesticide application, etc.) simplify and decrease the soil faunal community thereby reducing the beneficial contribution of these animals (Edwards and Lofty 1969, Hill 1985) while manures and fertilizers generally increase numbers and species of soil animals (Marshall 1977). Soil fauna in British Columbia and Sweden became more diversified under forage crops as a consequence of natural increase and immigration from surrounding areas (Carter et al. 1985). Abbott et al. (1979) found that large soil animals were virtually eliminated from the regularly cultivated soils.

Gray Luvisolic soils under a 49-year old forage stand and a three year old forage stand in a forage/grain rotation were compared to a virgin forest soil (Martin et al. 1987) and it was observed that while the forage stand increased soil C, N and biomass in an A horizon a concomitant increase in soil macro- and mesofaunal activity was not found. By contrast Berg and Pawluk (1984) found that soil mesofauna were most active under vegetative covers of alfalfa and fescue and least active under fallow on a cultivated Gray Luvisolic soil.

A study of the faunal dynamics of a Gray Luvisol indicated that the nematodes and microarthropods were greater in dry mass (g m^{-2}) in the oat compared to alfalfa plots (Fyles et al. 1987). The rooting systems of alfalfa and oats provided markedly different sized rhizospheres. Alfalfa has a single tap root with relatively few, small lateral branches whereas oats have many well-branched, fine roots. The oat crop provides more niches for microbes and fauna (Fyles et al. 1987). In a further study of the same soil, nematodes appeared to be significant regulators of decomposition and nutrient release through their interactions with microflora (Juma and Mishra 1988). It was also observed that the microbivore nematodes were the major group in cultivated soils while plant parasitic nematodes build up to greater numbers in the presence of perennial living roots.

1.2.6.3 Microbial Biomass

Microbial biomass of a Gray Luvisolic soil was greater after 50 years of forage than in a three year old forage stand from a forage/grain rotation or a virgin forest soil (Martin et al. 1987). The microbial biomass was significantly greater in an alfalfa than oat plot (Fyles et al. 1988). Campbell and Biederbeck (1982) observed that changes in microbial numbers and mineral N were correlated with soil depth, available C and environmental conditions. The dynamics of the microbial biomass and water-soluble organic C, and the quality of the organic component after 50 years of cropping a Luvisolic soil to 5-year (wheat, oats, barley, forage, forage) and 2 year (wheat, fallow) cropping systems was different (McGill et al. 1986). The soil of the 5-year rotation had 40 % more soil N and 12 % more microbial N than that of the 2-year rotation. Within these same cropping systems manure additions doubled microbial N compared to control or fertilized plots (NPKS).

1.2.6.4 C and N Dynamics

The turnover of microbial and soluble C was more rapid in a wheat-fallow than in a 5 year rotation with 3 years of cereals and 2 years of forage (McGill et al. 1986). More $^{14}CO_2$ was released from a Gray Luvisol than a Black Chernozem when labelled glucose was added (Juma et al. 1984). The pulse labelling of a Black Chernozemic and Gray Luvisolic soil revealed that microbial C was much more active in the Gray Luvisol (43 %) compared to the Black Chernozen (17 %) while active microbial C (g m^{-2}) was the same (Dinwoodie and Juma 1988). In another study of the same soils, it was observed that even though the microbial N in the surface horizon (0-30 cm) was greater for the Black Chernozem the microbial N for the Gray Luvisol made up a larger proportion of total soil N (1.6 compared to 0.9 %). The food web was more active for the Gray Luvisolic compared to the Black Chernozemic soil mainly because of greater C and water availability (Rutherford and Juma 1989a, Rutherford and Juma 1989b). This was interpreted from the greater CO_2-C:microbial C ratio, lower flush C:N ratio and greater protozoa population:soil C ratio for the Gray Luvisolic soil.

1.3 SUMMARY

Luvisolic soils are important agriculturally, as these soils are being farmed throughout Canada. In the next few decades Luvisolic soils will become more significant agriculturally as much of the better suited land for agriculture near urban centres is lost to the pressures of development and more marginal land is brought into production. Generally Luvisolic soils also have poorer a shorter and cooler growing season for plants as these soils are located in marginal areas. Problems in the management of these soils have been recognized and pertain mainly to the low clay, nutrients and organic matter contents of the structurally weak A horizon and the undesirable properties of the dense B horizon which restrict water percolation and root penetration.

Special management systems are required to maintain Luvisolic soils productive as the weak structure of the A horizon is easily destroyed. Cropping systems that provide a high degree of protection of the surface soil by providing trash or plant cover are desirable to maintain or improve the surface characteristics and biological activity of these soils. Reduced tillage is also beneficial as structure is protected from deterioration by tillage operations. Crops or mechanical methods that can loosen and open the B horizon are also required to improve internal soil water drainage and providing a greater rooting zone for the crops grown.

Luvisolic soils can be farmed successfully as long as their problems are addressed through proper management. Organic matter of the surface soils need to be maintained or improved and internal drainage needs to be improved to provide a improved rooting environment and increase the trafficability of the soil.

1.4 STUDY OBJECTIVES

Gray Luvisolic soils have not received the required research in relation to their importance in agriculture (McFall 1954, Robertson and McGill 1983). These soils have been studied extensively at the Beaverlodge Research Station in the Peace River region of Alberta (Soon 1986) and the Lacombe Research Station at Lacombe, Alberta, but not to the same degree as other major agricultural soils. The Breton Plots, of the University of Alberta, have been in operation for over 60 years and have provided considerable management information about nutrient deficiencies, yield responses to fertilizers and the effects of cropping sequences or rotations (Robertson and McGill 1983). The Breton Plots are believed to be the only intensively studied long-term plots on Luvisolic soils in Canada and perhaps the world and provide a unique source of information (Cannon et al. 1984).

Research plots (Beaverlodge Long-term Cropping System Field Experiment) were established in 1968 near Beaverlodge also on a Luvisolic soil. This cropping system experiment was used to study and provide more information on the effects of management on Luvisolic soils. The objectives of this study were:

1) to determine soil water property changes under diverse cropping systems,
2) to determine soil aggregate distribution and stability under the different cropping systems,
3) to estimate the net nitrogen mineralization potentials of the soils from the different cropping systems,
4) to determine net nitrogen mineralization when cropping system soils are amended with plant residues, and
5) to synthesize the impact of different management systems on the physical, chemical and biological properties of Gray Luvisolic soils.

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CHAPTER 2

The Design and Management of the Beaverlodge Long-term Cropping System Field Experiment

2.1 INTRODUCTION

The Beaverlodge Long-term Cropping System Field Experiment was initiated in 1968 (Soon and Broersma 1986). This long-term field experiment included continuous cropping systems of barley, legume, grass, and alternating barley and forage.

2.2 MATERIALS AND METHODS

2.2.1 Location and Soil

The Beaverlodge Long-term Cropping System Field Experiment site is located 6 km east of the Beaverlodge Research Station in the Peace River region of Alberta (Fig. 2.1). The soils are Luvisolic and are of the Gray and Dark Gray sub-groups. The plot area has been mapped and contains three soil series (Esher, Albright and Hythe) with inclusions of about 10 % of two other soil series (Snipe and Hazelmere) (Appendix 8.1, Hennig 1965). The soils are imperfectly drained with undulating and rolling topography and have surface textures of loam to clay loam.

2.2.2 Plot Preparation and Sampling

The plot area had originally been brush cut in the fall and winter of 1956-57. The regrowth was gyro-mowed in June 1967 and the area broken with the moldboard plow in July of the same year. The depth of plowing was approximately 15 cm. In the spring of 1968 the land was prepared for the various cropping systems by discing and harrowing and then establishing the plot boundaries as per Fig. 2.2 before seeding. The soils from each cropping system was sampled in 1968 prior to the establishment of the plots (0-15, 15-30 and 30-45 cm) and after 1977 regularly (to a depth of 90 cm) to determine plant availble nurtrients from soil-testing (Appendix 8.5).

2.2.3 Plot Lay-out, Design and Cropping Systems

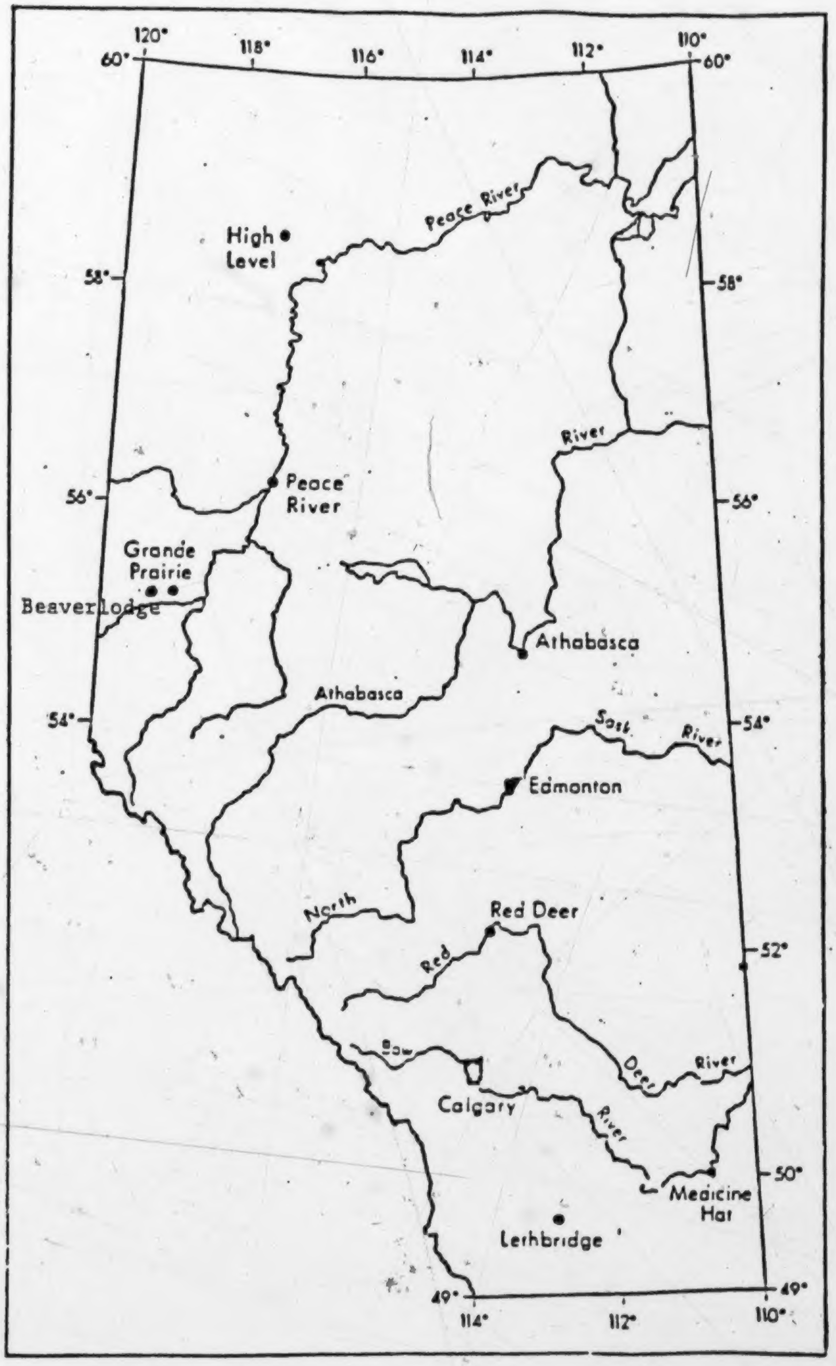
The plot lay-out consisted of a randomized block design, with each block replicated four times (Fig. 2.2). Each plot (one cropping system replicate) measured 22 by 58 m with 5 plots per block (replicate). The total area covered by the plots was just over 2.5 ha. The cropping systems that are part of this long-term experiment consists of:

1) continuous barley (CB),
2a) barley (Bf): 3 years barley followed by 3 years forage,
2b) forage (Fb): 3 years forage followed by 3 years barley,
3) continuous grass (CG) and
4) continuous legume (CL).

The CB cropping system and the barley component of the Bf cropping system in the rotation was seeded at 110 kg ha^{-1} of barley (Hordeum vulgare cv. 'Galt'). The forage component of the Fb cropping system initially was a mixture of brome grass (Bromus inermis L., cv. 'Carlton') and alfalfa (Medicago sativa L., cv 'Beaver') seeded at rates of 6.7 and 5.6 kg ha^{-1}, respectively. The legume component of the forage mixture and CL cropping gsytems were changed to and red clover (Trifolium pratense L., cv 'Norlac') in 1978. The CL cropping system plots were seeded at a rate of 9 kg ha^{-1}. The CG cropping system plots were seeded to bromegrass at a rate of 11.2 kg ha^{-1}.

2.2.4 Fertilizer Sources

The main source of fertilizer nitrogen (N) was ammonium nitrate (34-0-0), which was broadcast. Phosphorus (P) was mainly supplied as ammonium phosphate (11-48-0). For forage crops, fertilizers were broadcast in early spring and following harvest of the first cut if soil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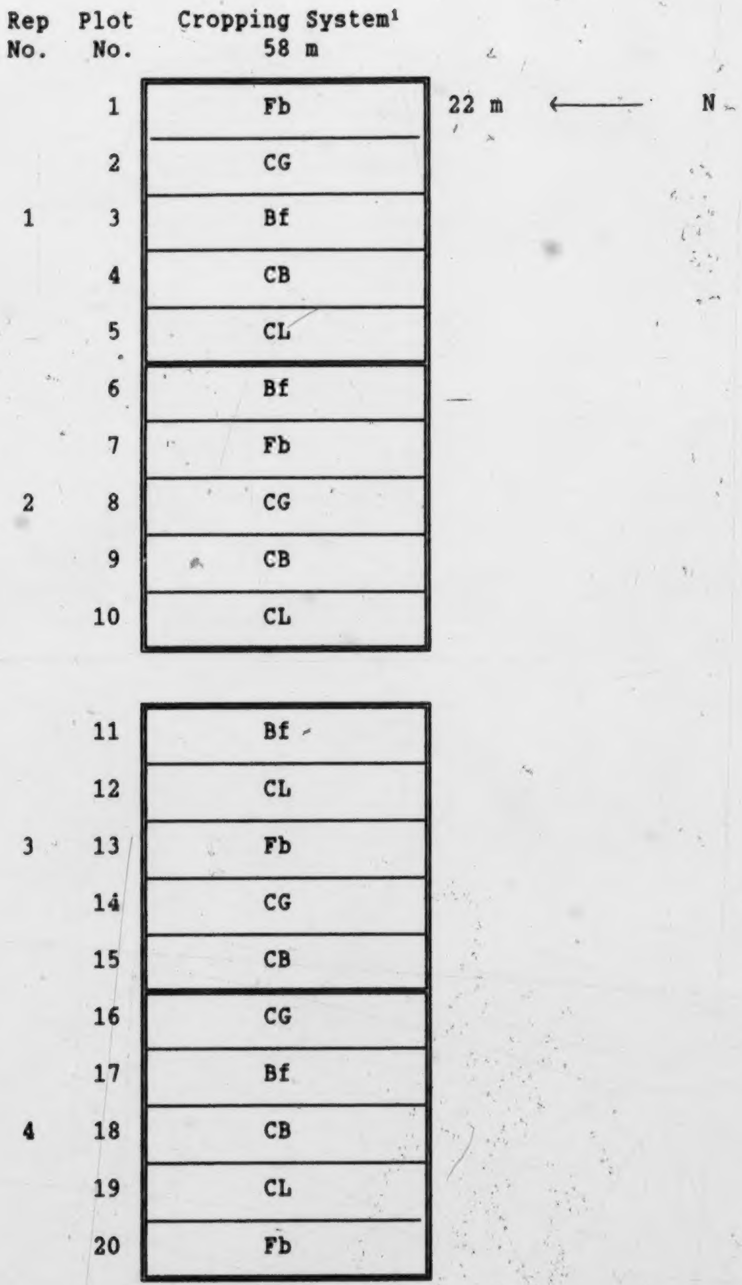
High Level
Peace River
Peace River
River
Grande Prairie
Beaverlodge
Athabasca
Athabasca
Sask.
River
Edmonton
North
Red Deer
Red
Deer
River
Bow
Calgary
River
Medicine Hat
Lethbridge

Fig. 2.1 Location of Beaverlodge Long-term Cropping System Field Experiment in relation to the province of Alberta.



Rep No.	Plot No.	Cropping System[1]
1	1	Fb
	2	CG
	3	Bf
	4	CB
	5	CL
2	6	Bf
	7	Fb
	8	CG
	9	CB
	10	CL
3	11	Bf
	12	CL
	13	Fb
	14	CG
	15	CB
4	16	CG
	17	Bf
	18	CB
	19	CL
	20	Fb

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[1] -CB-continuous barley, Bf-barley/forage, Fb-forage/barley, CG-continuous grass and CL-continuous legume.

Fig. 2.2 The lay-out of the plots for the Beaverlodge Long-term Cropping System Field Experiment, located 6 km east of the Beaverlodge Research Station.

moisture conditions appeared sufficient for a second harvest. Fertilizers for barley were broadcast in early spring and incorporated into the soil before seeding. In 1985 and subsequent years potassium (K) was applied at fairly low rates to all plots as potassium chloride (0-0-60).

2.2.5 Cultural Management of the Long-term Plots

The cultural management history for the plots from the original land clearing in 1956 up to 1987 was summarized and tabulated (Table 2.1). Shallow moldboard plowing was used to bring the plot area into production in the late summer of 1967. In the spring of 1968 the whole plot area was prepared for seeding by discing and harrowing. Seeding occurred late on June 1 of that year for each of the cropping systems. Only the cropping systems with barley (CB and Bf) were harvested for grain during the first year. The cropping systems seeded to forage did not establish quickly and produce enough growth to warrant harvesting during the year of establishment.

The first harvests from the forage cropping systems were obtained on June 25, 1969 (the second year of the experiment). The barley for the CB and Bf cropping systems was seeded May 21 in 1969 but was not harvested until October 14. Management of the Beaverlodge Long-term Cropping System Field Experiment was similar over the years and the dates of any cultural technique such as discing, harrowing, fertilizing, seeding and harvesting varied with the weather and soil conditions.

Seeding dates over the 20 years ranged between May 5 to June 8. Land preparation for seeding was usually done by fall plowing and/or discing and then discing, fertilizing and harrowing prior to seeding. At the end of the third year of forage production, the Fb cropping

Table 2.1. The field operations and dates for the Beaverlodge Long-term Cropping System Field Experiment for the years 1956 to 1986.

Year	Date	Cropping Systems	Cultural Techniques
1956	Winter	All	land cleared (Breaking Project)
1957-67			land used to evaluate land clearing techniques (replicates 1 and 2 were only used for the Beaverlodge long-term cropping experiment)
1967	Aug 16	All	plowed
1968	June 1	All	seeded and fertilized
	Sept 1	CB, Bf[1]	harvest of barley
1969	May 21	CB, Bf	seeded and fertilized
	June 25	CG, CL, Fb	1st hay cut, fertilized
	Oct 14	CB, Bf	harvest of barley
1970	May 7,8	All	fertilized
	May 12	CB, Bf	disced
	13,14	CB, Bf	double disced, seeded and fertilized
	June 23	CG, CL, Fb	1st hay cut
	Sept 17	CB, Bf	harvest of barley
	Sept 21	CG, CL, Fb	2nd hay cut
	Sept 24	CB, Fb, Bf	plowed
1971	June 3	CB, Fb, Bf	seeded and fertilized
	July 26	CG, CL	1st hay cut
1972	May 18	CB, Bf	double disced
	May 25	CB, Bf	double disced and harrowed
	May 29	CB, Bf	seeded and fertilized
	June 30	CG, CL, Fb	1st hay cut
	July 21	CG, CL, Fb	fertilized
	Aug 29	CB, Bf	harvest of barley
1973	May 18	CB, Bf	disced and harrowed
	May 25	CB, Bf	rotovated and harrowed
	May 28	CB, Bf	seeded and fertilized
	June 1	CB, Bf	fertilized and harrowed
	June 29	CG, CL, Fb	1st hay cut
	Aug 7,8	CG, CL, Fb	plowed and disced
	Sept 4	CB, Bf	harvest of barley
1974	June 5	CB, CG, CL	double disced
	June 5	Bf	double disced and harrowed
	June 7	CB, Bf	seeded and fertilized
	June 7	CL	seeded

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Table 2.1. Continued

Year	Date	Cropping Systems	Cultural Techniques
1974	June 10	CG	seeded and fertilized
	June 10	Fb, CB	fertilized
	July 29	Fb	1st hay cut
	Sept 25	CB, Bf	harvest of barley
	Oct 13	CB, Bf	rotovated
	Oct 16	CB, Bf	disced
1975	May 22	CB	disced and harrowed
	May 22	CG, CL	fertilized
	May 23	CB, Bf	seeded and fertilized
	July 4	CG, Fb	1st hay cut
	July 9	CL	plowed
	Sept 15	CB, Bf	harvest
	Oct 2	Fb, CG	removed overages
1976	May 7	Bf	disced and harrowed
	May10,11	CB, CL, Bf	seeded and fertilized
	May 11	Fb	fertilized
	May 11	CB, Bf	harrowed
	July 22	CG, Fb	1st hay cut
	July 30	CG	fertilized
	July 30	CL, Fb	plowed and disced
	Aug 30	CB, Bf	harvest
	Oct 1	CG	2nd hay cut
	Oct 26	CL, Fb	rotovated
	Nov 2	CB, Bf	swathed
	Nov 18	CB, Bf	removed overages
1977	May 6	CB, Bf, CL	fallow
	June 3	Fb	underseeded
	June 30	CG	harvest
	Aug 28	Fb	harvest
	Oct	All	plowed and disced
1978	May 19	All	sub-soiled and harrowed
	May 26	CL, Bf	picked rocks
	May 30	All	seeded and fertilized
	June 2	CB, Bf	packed
	July 18	CG, CL, Fb	mowed
	Sept 11	CB, Bf	harvest
	Sept 14	CB, Bf	swathed
	Oct 11	CB	removed overages
1979	May 30	CB, Bf	sub-soiled and harrowed
	June 1	CB, Bf	harrowed, seeded and fertilized
	June 1	CG, CL, Fb	fertilized
	June 4	CB, Bf	packed

Table 2.1. Continued

Year	Date	Cropping Systems	Cultural Techniques
1979	July 4	CG, CL, Fb	1st hay cut
	Sept 4	CB, Bf	harvest of barley
	Sept 12	CB, Bf	swathed
	Sept 28	CG, CL, Fb	2nd cut
	Oct 11	CB	removed overages
1980	May 9	CG, CL, Fb	fertilized
	May 12	CG, Fb	fertilized
	May 13	CB, Bf	seeded and fertilized
	June 25	CG, CL, Fb	1st hay cut
	July 9	CG, CL, Fb	fertilized
	Sept 2	CB, Bf	harvest of barley
	Oct 1	CG, CL, Fb	2nd hay cut
1981	May 25	CB, Fb, Bf	seeded and feritlized
	May 25	CG, CL	fertilized
	June 23	CG, CL	1st hay cut
	July 1	CB, Fb, Bf	sprayed with herbicide
	Aug 21	CB, Fb	harvest of barley
	Sept 10	CB, Fb	cultivated and disced
	Sept 16	Bf	1st hay cut
	Sept 30	CB, Fb	disced
1982	May 25	CB, Fb	fertilized
	May 31	CB, Fb	seeded and fertilized
	June 1	CG, CL, Bf	fertilized
	June 12	CG, CL, Bf	1st hay cut
	Sept 1	CG, CL, Bf	2nd hay cut
	Sept 3	CL, Bf	plowed
	Sept 10	CB, Fb	harvest of barley
1983	June 6	CL	rotovated
	June 6	CB, CL	fertilized
	June 8	Fb, CB	seeded and fertilized
	June 10	CL	seeded
	July 25	CG	1st hay cut
	Sept 19	CB, Fb	harvest of barley
	Sept 20	CG, Fb	removed overages
	Oct 19	Fb	cultivated
1984	Apr 19	CB, Bf	disced
	Apr 27	CB, Bf	disced and harrowed
	May 15	Al	fertilized
	June 16	CG, Cl, Fb	1st hay cut
	Sept 20	CG, Cl, Fb	2nd hay cut

Table 2.1. Continued

Year	Date	Cropping Systems	Cultural Techniques
1985	May 10	All	fertilized
	May 14	CB, Bf	disced and harrowed
	May 15	CB, Bf	seeded
	June 25	CB, Bf	sprayed with Buctril M
	July 8	CG, CL, Fb	1st hay cut
	Aug 10	CB, Bf	harvest of barley
	Oct 4	CB, Bf	cultivate
1986	May 28	All	fertilized
	May 29	CB, Bf	disced
	June 2	CB, Bf	seeded and fertilized
	June 18	CG, CL, Fb	1st hay cut
	Aug 8	CG, CL, Fb	2nd hay cut
	Sept 3	CB, Bf	harvest of barley
	Sept 24	CB, Bf	cultivated
1987	May 4	All	fertilized
	May 5	CB, Bf	seeded and fertilized
	May 27	CG	sprayed with herbicide
	June 17	CG, CL, Fb	1st hay cut
	June 19	CG, CL, Fb	fertilized
	Sept 8	CG, CL, Fb	removed overages
	Sept 17	CB, Bf	swathed, took yields
	Sept 22	CB, Bf	disced
	Oct 1	CB, Bf	cultivated

[1]-see Fig. 2.2.

system plots were plowed and disced in the late summer and during the fall to prepare the land for the Bf cropping system the following year. In 1977 the CB, Bf and CL cropping systems were fallowed because of very wet conditions during May and July. Over the 1977 growing season, there was an excess of moisture (+7 mm over the growing season) above evapotranspiration. (Appendix 8.2)

Over the years, the trial area has been subjected to a variety of cultivation treatments. The whole cropping system experiment was plowed and disced in the fall of 1977 while in the spring of 1978 the same area was subjected to a sub-soiling treatment to loosen the B horizon to a depth of about 45 cm. This sub-soiling treatment was repeated in 1979 only for the CB and Bf cropping systems. A rotovator was used in three years, 1973, 1974 and 1976. In 1973 the rotovator was used prior to seeding to prepare the seed bed while for the other two years it was used in the fall to elliminate the existing crop. Cropping systems requiring land preparation were usually plowed, disced and/or cultivated the preceding fall. These cropping systems were left rough over the winter and the seed bed was prepared by discing and harrowing in the spring.

The harvesting dates of the different cropping systems varied with the year. The latest harvest of barley from the Bf and CB cropping systems occurred in 1969 on October 14. During the other years the extreme harvest dates ranged between August 9 (1985) to September 19 (1983). The first harvest of the forage crops from the Fb, CG and CL cropping systems generally occurred during the last two weeks of June. The earliest first harvest occurred on June 12 in 1982 and the latest first harvest on July 22 of 1976. Second harvests were taken in the fall when there was enough re-growth. Two harvests were taken from the forage cropping systems in eight of the twenty years (Table 2.1 and Appendix 8.3).

2.2.6 Fertilizer Amounts Applied

Fertilizer rates and applications varied over the years (Table 2.2). For the first year, N and P were applied to only the cropping systems that were growing barley (CB and Bf cropping systems). In the second year, 1969, this was reversed with the forage cropping systems receiving fertilizer but not the barley plots (no reason was given for this). In 1971, for no apparent reason, fertilizer was not applied to any of the cropping systems. The only other year when no fertilizer was applied was 1977 when it was too wet in May and the CB, Bf and CL cropping system areas were summerfallowed. After 1977 fertilizer applications were based on tests done on soil sampled in the fall. The CG cropping system over the 20 years received the greatest amount of N fertilizer, 1200 kg ha^{-1} of N (60 kg annually). The CL cropping system received 390 kg ha^{-1} of N applied over the same period or about 20.5 kg ha^{-1} of N for each year. The three remaining cropping systems had between 875 and 985 kg ha^{-1} of N applied from 1968 to 1987 for an annual average of 46 kg ha^{-1} of N.

Phosphorus was applied at lower rates with all applications averaging less than 30 kg ha^{-1} of P_2O_5. The CG cropping system received the least total amount of P fertilizer at 160 kg ha^{-1} of P_2O_5 for the years 1968-1987 or an annual average of 8 kg ha^{-1} of P_2O_5. The CB, Bf, Fb and CL cropping systems received between 17 and 21 kg ha^{-1} of P_2O_5 annually. No K was applied until 1985 when all cropping systems received 34 kg ha^{-1} of K_2O annually until 1987.

Table 2.2. Record of amounts of fertilizer applied annually to the Beaverlodge Long-term Cropping System Field Experimental plots from 1968 to 1987.

Year	Cropping System[1]		Total Annual	
		N	P_2O_5	K_2O
			kg ha^{-1}	
1968	CB	7.4	32.3	0.0
	Bf	7.4	32.3	0.0
	Fb	0.0	0.0	0.0
	CG	0.0	0.0	0.0
	CL	0.0	0.0	0.0
1969	CB	0.0	0.0	0.0
	Bf	0.0	0.0	0.0
	Fb	12.3	53.8	0.0
	CG	38.1	0.0	0.0
	CL	12.3	53.8	0.0
1970	CB	45.5	32.3	0.0
	Bf	45.5	32.3	0.0
	Fb	32.2	32.2	0.0
	CG	38.1	0.0	0.0
	CL	12.3	53.8	0.0
1971	CB	0.0	0.0	0.0
	Bf	0.0	0.0	0.0
	Fb	0.0	0.0	0.0
	CG	0.0	0.0	0.0
	CL	0.0	0.0	0.0
1972	CB	73.3	37.6	0.0
	Bf	32.2	32.2	0.0
	Fb	73.3	37.6	0.0
	CG	30.2	15.7	0.0
	CL	9.9	43.0	0.0
1973	CB	61.9	37.6	0.0
	Bf	0.0	0.0	0.0
	Fb	61.9	37.6	0.0
	CG	0.0	0.0	0.0
	CL	0.0	0.0	0.0
1974	CB	64.5	32.3	0.0
	Bf	64.5	32.3	0.0
	Fb	57.1	0.0	0.0
	CG	57.1	0.0	0.0
	CL	0.0	0.0	0.0

Table 2.2. Continued.

Year	Cropping System	Total Annual		
		N	P_2O_5 kg ha^{-1}	K_2O
1975	CB	64.5	32.3	0.0
	Bf	32.2	32.2	0.0
	Fb	64.5	32.3	0.0
	CG	30.2	15.7	0.0
	CL	9.9	43.0	0.0
1976	CB	64.5	32.3	0.0
	Bf	57.1	0.0	0.0
	Fb	64.5	32.3	0.0
	CG	87.3	15.7	0.0
	CL	7.4	32.3	0.0
1977	fallow	0.0	0.0	0.0
1978	CB	87.3	48.4	0.0
	Bf	76.2	0.0	0.0
	Fb	87.3	48.4	0.0
	CG	114.2	0.0	0.0
	CL	38.1	0.0	0.0
1979	CB	44.3	30.8	0.0
	Bf	89.6	51.5	0.0
	Fb	44.3	30.8	0.0
	CG	73.2	0.0	0.0
	CL	44.3	30.8	0.0
1980	CB	95.9	30.8	0.0
	Bf	90.0	26.9	0.0
	Fb	95.8	30.8	0.0
	CG	135.3	0.0	0.0
	CL	62.7	107.5	0.0
1981	CB	44.3	28.6	0.0
	Bf	38.1	0.0	0.0
	Fb	44.3	28.6	0.0
	CG	76.2	0.0	0.0
	CL	38.1	0.0	0.0
1982	CB	44.3	28.6	0.0
	Bf	50.4	57.1	0.0
	Fb	38.1	0.0	0.0
	CG	76.2	0.0	0.0
	CL	12.3	57.1	0.0

Table 2.2. Continued.

Year	Cropping System	Total Annual N	P_2O_5 kg ha^{-1}	K_2O
1983	CB	55.0	32.3	0.0
	Bf	55.0	32.3	0.0
	Fb	47.6	0.0	0.0
	CG	47.6	0.0	0.0
	CL	47.6	0.0	0.0
1984	CB	47.6	0.0	0.0
	Bf	47.6	0.0	0.0
	Fb	95.2	0.0	0.0
	CG	95.2	0.0	0.0
	CL	95.2	0.0	0.0
1985	CB	44.9	28.2	33.6
	Bf	44.9	28.2	33.6
	Fb	112.0	28.2	33.6
	CG	112.0	56.4	33.6
	CL	0.0	28.2	33.6
1986	CB	66.6	27.7	33.6
	Bf	66.6	27.7	33.6
	Fb	0.0	27.7	33.6
	CG	66.6	27.7	33.6
	CL	0.0	27.7	33.6
1987	CB	72.8	56.3	33.6
	Bf	72.8	56.3	33.6
	Fb	0.0	27.7	33.6
	CG	123.7	27.7	33.6
	CL	0.0	27.7	33.6
1968-87 Totals	CB	984.6	548.4	100.8
	Bf	875.3	476.8	100.8
	Fb	925.2	412.5	100.8
	CG	1201.2	158.9	100.8
	CL	390.0	504.8	100.8
1968-87 Means	CB	49.2	27.4	5.0
	Bf	43.8	23.8	5.0
	Fb	46.3	20.6	5.0
	CG	60.1	7.9	5.0
	CL	19.5	25.2	5.0

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[1] -see Fig. 2.2.

2.2.7 Plot and Management Variability

Management of the Beaverlodge Long-term Cropping System Field Experiment was not consistent and according to the original established plan. The influence of inclement weather, changes in crops grown, changes in personnel directing the plots and soil variabilty were all factors resulting in inconsistancy in maintaining these plots.

Luvisolic soils have inherent problems that make their management difficult. Inclement weather has had a strong influence on the timing of cultural operations and the growth of crops. During the year 1968 to 1987 there were a number of years when soil conditions were unfavourable for seeding, growth of the crop and/or harvesting. In 1977 and 1984 the cropping systems growing barley were fallowed as a result of wet weather and 1983 was also very wet. The years 1974, 1982 and 1986 were very dry.

The legume grown initially was alfalfa but this was changed to red clover after 1978. The change in the legume component of the Fb and CL cropping systems was changed because of alfalfa plant breeding work being conducted in the vicinity of the plots. During the interm period of 1974 to 1978 the CL cropping system plots were mostly fallowed before a final decision was made to grow red clover. Personnel changes during the years and not having one person responsible for the plots resulted the lack of consistancy necessary to direct the work and summarize the results.

Plot variability exists in these plots because of the large plot area. Significant replicate differences were observed for some of the chemical parameters measured such as carbonate C, pH, exchangeable cations of calcium, magnesium, potassium and sodium. Replicate differnces for plant available NO_3-N, P and K were not determined as samples were bulked.

2.3 REFERENCES

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CHAPTER 3

The Effects of Different Cropping Systems on Soil Water Properties of a Luvisolic Soil

3.1 INTRODUCTION

Soil structure is strongly influenced by current and long-term cropping practices. Changes in soil structure because of cultural practices such as tillage have a pronounced effect on bulk density, porosity, aeration, infiltration, water storage, water transport characteristics and runoff (Cameron et al. 1981). Tillage shears and pulverizes the soil, exposing new surfaces to microbial oxidation (Rovira and Greacen 1957) and this decreases soil organic matter. Tillage thus deteriorates soil structure (Shutt 1925, Low 1972, Cameron et al. 1981).

Tillage pulverizes the soil, resulting in smaller aggregates or particles that are oriented by the process and packed more tightly when settled. Structural characteristics as bulk density, porosity, aeration and water storage are affected. The bulk density of cultivated fields is generally higher than that of native grassland or forest soils. The addition of fertilizers (Osborne et al. 1978), organic residues (Ferguson 1967, Black 1973), mulches (Black and Siddoway 1979) or manures (Williams and Cooke 1961) decreased the bulk density of cultivated fields. Dew (1968) found a slight increase in bulk density, as the number of cultivations increased on fallow from two to 12. Air porosity is inversely related to bulk density (Baumer and Bakermans 1973) and decreases with tillage. This, in the absence of other changes, would be expected to reduce hydraulic conductivity, reduce aeration and restrict root growth (Russell 1978).

The size and continuity of individual pores, rather than the total pore volume, are the most important factors influencing aeration. Porosity and pore size distribution influence the water storage and water transport characteristics of a soil. Tillage reduces the macropore space and produces a discontinuity in pore space between the cultivated surface and the subsoil (Bolton et al. 1979). Infiltration rates and percolation are reduced and, therefore, runoff increases under tillage. Shaykewich (1970) found that water storage at 0.03 MPa (2.45 pF) was greater for disturbed soil compared to undisturbed soils, but at tensions of 1.5 MPa (4.20 pF) a similar trend was observed in only four out of seven soils, with only one being significantly greater. Water holding capacity was also related to texture and organic matter, which explained 40 % of the variability (Shaykewich 1980).

Crop cover has a pronounced effect on infiltration and runoff. Cropping practices that require tillage reduce ground cover and increase runoff. A crop or residue mulch cover on the soil surface reduces the impact of rain and thereby reduces the energy available for breaking down soil structure (Marstan and Doyle 1978). In Australia (New South Wales) an increase of ground cover from 20 to 60 % reduced the average annual runoff from 175 to 30 mm (Lang 1979). Runoff was slight when ground cover exceeded 75 % but increased rapidly (curvilinearly) when ground cover was less than 75 %. Cropping systems have a dramatic influence on runoff and erosion. This was shown by Toogood (1963) with soil losses of 0.007, 0.94 and 2.0 t ha^{-1} annually from virgin sod, stubble after fallow, and fallow after wheat, respectively, over a 10 year period (1950-60). Similar trends were observed by Chanasyk and Woytowich (1987) with spring snowmelt runoff in the Peace River region.

Water erosion is caused by the impact of rain drops that breakdown of the soil aggregates, detaching soil particles from the soil surface and transporting them, usually down hill (Rosewell and Marstan 1978). Skidmore et al. (1975) found that after six h of infiltration, a newly broken sod and 60-year cultivated field had constant infiltration rates of 0.95 and 0.13 cm h^{-1}, respectively. Mazaruk et al. (1955) showed that the greatest infiltration was obtained in continuous alfalfa while continuous row cropping had much lower rates.

In this study, the effects of the diverse cropping systems from the Beaverlodge Long-term Cropping System Field Experiment on the soil water properties were studied and reported. The soil water properties assessed for each cropping system included: bulk density, soil water content on a mass and volume basis in the profile after the growing season, saturated hydraulic conductivity, water retention, available water holding capacity, infiltration rate and water accumulation.

3.2 MATERIALS AND METHODS

3.2.1 Cropping Systems and Soil Sampling

Soil samples were collected in 1983 (early September) from the Beaverlodge Long-term Cropping System Field Experiment located six km east of the Beaverlodge Research Station in the Peace River region of Alberta. The experimental plot area was established in 1968 and is situated on Luvisolic soils.

The cropping systems consisted of:

1) continuous barley (CB),
2a)barley/forage (Bf) (3 yr of barley followed by 3 yr of forage),
2b)forage/barley (Fb) (3 yr of forage followed by 3 yr of barley),
3) continuous grass (CG) as bromegrass and
4) continuous legume (CL) as red clover.

The CB and Bf cropping systems were seeded annually to barley (Hordeum vulgare cv. 'Galt') and harvested as grain. The forage component of the Fb and Bf cropping system consists of a mixture of bromegrass (Bromus inermis, cv. 'Carlton') and red clover (Trifolium pratense, cv. 'Norlac'). The CG and CL cropping systems were seeded to bromegrass and red clover, respectively. Prior to 1978 the legume component of the CL and Fb cropping systems were seeded to alfalfa (Medicago sativa, cv. 'Beaver'). The forages were harvested as hay. A more detailed description of the cropping systems and their management is presented in Chapter 2.

Representative bulk soil samples were collected by taking eight 5-cm diameter cores from each plot to a depth of 120 cm with a truck mounted soil corer. The cores were segmented into depths of 0-15, 15-30, 30-45, 45-60, 60-90 and 90-120 cm. All except three cores, which were used for root mass determinations, were air-dried and passed through a 2-mm sieve. Three separate core samples were taken at each of three depths (0-15, 15-30 and 30-45 cm) for determination of saturated hydraulic conductivity.

3.2.2 Methodology

The gravimetric method was used to determine soil moisture. Three of the eight core samples from each depth increment were oven-dried at 105°C to a constant weight in a forced-air oven (Gardner 1965). The gravimetric moisture was calculated as the ratio of the mass of H_2O to the dry mass of the soil sample. Bulk density was calculated from the dry weight of the core samples used to determine soil water content (Blake 1965).

Saturated hydraulic conductivity (K sat) was determined in the laboratory by the falling head method for three depths for each of the cropping systems (Klute, 1965). A double-cylinder, hammer driven core sampler was used to obtain relatively undisturbed 7.6 cm diameter by 7.6 cm long cores. Samples were sealed in plastic bags and placed inside waxed-paper food containers for transportation to the laboratory. Moisture retention curves were obtained from disturbed samples by the method of Richards (1965) at tensions of 0.03, 0.1, 0.5 and 1.5 MPa. Plant available water was calculated by difference between the water content at field capacity (0.03 MPa) and at the permanent wilting point (1.5 MPa).

The rate of water intake in the field was determined using a double-ring infiltrometer (Bertrand 1965). Two sets of three double rings were used for a total of six determinations at a time. The inner ring had diameters of 30.5, 32 and 33 cm while the outer ring had diameters of 61, 63.5 and 66 cm. The metal rings were driven into the soil vertically about five cm using a metal plate and sledge hammer. Infiltration data were collected at times of 1, 2, 3, 5, 10, 15, 20, 30, 60, 90, 120 min and then hourly for an 8-h period. A head of 5-10 cm was maintained and readings taken with a floating gauge. The weather at time of sampling was mostly sunny till the final three h of the last set when it showered lightly. Rain water was excluded from the cylinders by covering with plastic sheets. The accumulated depth (mm) of water infiltrated over 8 h was also calculated.

3.2.3 Statistical Analysis and Calculations

The design of the experimental field plots was a randomized block with four replications. Data were subjected to statistical analysis using SAS (1982) and SRS (Agriculture Canada 1984) software packages.

Treatment and error variances were partitioned using analysis of variance techniques. Duncan's New Multiple Range test was used to compare means after a significant F-test was established. Saturated hydraulic conductivities were transformed to a logarithmic form because the standard deviations were of the same magnitude as the means and the most effective transformation is a log transformation (Little and Hills 1978). Infiltration rates and accumulated depth of water were fitted to a non-linear power equation ($I = aT^n$) (Hanson et al. 1980) with time as the independent variable. In the above equation, I is equal to the infiltration rate (mm) or accumulated water (mm), T is time in minutes (on a logarithmic scale), 'a' is a constant which is the value on the y-axis when T on the x-axis has a value of 1, and n is the slope of the line.

3.3 RESULTS AND DISCUSSION

3.3.1 Bulk density

Bulk density increased with depth (Table 3.1). The bulk densities above 30 cm were significantly different from those below 30 cm ($P \leq 0.0001$), an indication of the depth of cultivation over the years and the depth of the more dense and compacted Bt horizon. The mean bulk density for all cropping systems was 1.10, 1.10, 1.45, 1.46 and 1.47 Mg m^{-3} for the 0-15, 15-30, 30-45, 45-60 and 60-90 cm depth intervals, respectively. Differences among cropping systems were significant ($P \leq 0.0036$). The means for the profiles ranged from 1.27 for the CL cropping system to 1.39 Mg m^{-3} for the Bf cropping systems. There was also a significant interaction between cropping system and depth. The highest bulk density of the surface horizon was observed in

Table 3.1 Soil bulk density for the different depth intervals for the cropping system.

Depth cm	CB[1]	Bf	Fb	CG	CL
			Mg m^{-3}		
0-15	1.11	1.13	1.06	1.18	1.02
15-30	1.15	1.12	1.11	1.10	1.05
30-45	1.37	1.54	1.51	1.42	1.42
45-60	1.33	1.55	1.56	1.43	1.45
60-90	1.44	1.60	1.46	1.42	1.43
	1.28 C[2]	1.39 A	1.34 B	1.31 BC	1.27 C

[1] CB-continuous barley, Bf-barley/forage, Fb-forage/barley, CG-continuous grass and CL-continuous legume.

[2] means followed by different letters are significantly different at $P \leq 0.05$.

the CG cropping system, which had not been reseeded or cultivated since 1978, while the lowest was for the CL cropping system.

3.3.2 Soil Water Content

Soil water was determined near the end of the growing season (September 1983). Soil moisture was significantly different among cropping systems and with depth. There was no interaction between cropping system and depth (Table 3.2).

Water content was significantly lower at all depths above 60-90 cm for the CL cropping system than for the other cropping systems ($P \leq 0.05$). The CL cropping system had an actively growing crop (new seeding June 10th) at time of sampling while the two other cropping systems with forage (CG and Fb) had been harvested as hay at the end of July (25th). Soil water for the CB cropping system was the highest but not significantly greater than for the CG, Fb or Bf cropping systems.

Table 3.2 Soil water content expressed on a mass and volume basis for cropping system profiles at time of infiltration determination (means of four replicates, September 1983).

Interval cm	Cropping System CB[1]	Bf	Fb	CG	CL
			water content $g\ g^{-1}$ x100		
0-15	22.1	20.7	21.6	24.8	18.3
15-30	23.6	21.8	21.1	21.4	18.4
30-45	28.0	27.2	26.8	27.1	23.5
45-60	27.2	27.0	27.9	27.0	24.6
60-90	25.8	25.7	26.0	23.3	25.0
Mean	25.3 A[2]	24.5 A	24.7 A	24.7 A	21.9 B
			Volume-basis (cm water depth $interval^{-1}$)		
0-15	3.65	3.50	3.45	4.38	2.77
15-30	4.06	3.65	3.47	3.52	2.87
30-45	5.72	6.31	6.05	5.76	5.01
45-60	5.41	6.29	6.54	5.77	5.33
60-90	11.12	12.34	11.40	9.92	10.68
Total	30.0 AB[3]	32.1 A	30.9 AB	29.3 B	26.7 C

Analysis of Variance

Source of Variation	df	mass water (%) mean square	Pr.>F[4]	volume water content mean square	Pr.>F[4]
Rep	3	10.75	NS	0.36	NS
Cropping System(CS)	4	34.48	0.0006	2.46	0.0010
Error a	12	3.21		0.26	
Depth(D)	4	143.89	0.0001	29.17	0.0001
CS*D	16	6.29	NS	0.61	0.0084
Error b	60	5.40		0.26	

[1] see Table 3.1.

[2] Duncan's Multiple Range Test, different uppercase letters designate statistical differences ($P \leq 0.05$) among columns means.

[3] Volumetric water content determined for depth of 0-90 cm.

[4] The significance probability associated with the F statistic.

Water distribution within the profile for each cropping system was similar. At the time of sampling, the 0-15 and 15-30 cm soil depth interval had the lowest amounts of stored soil water. The amount of soil water in the profile increased to a maximum at the 30-45 cm depth interval and then decreased for the 45-60 and 60-90 cm depth intervals. The amount of soil water in the 60-90 cm depth interval was the lowest for the CG cropping system.

There was a significant difference in water content (volume basis) among cropping systems ($P \leq 0.0010$) and with depth ($P \leq 0.0001$). A significant interaction between cropping system and depth ($P \leq 0.0084$) was also observed (Table 3.2).

Volumetric water content of the CL cropping system was significantly lower than that of the other cropping systems. For the remaining cropping systems, only the CG cropping system had significantly less volumetric water than the Bf cropping system. Average volumetric water contents of the 0-15 and 15-30 cm depth intervals were significantly lower than for the depth intervals below 30 cm. Interactions between cropping system and depth were observed with the CL cropping system having the least volumetric water content in the depth intervals above 60 cm. The CG cropping system had the highest volumetric water in the surface and the least at depths below 60 cm.

The soil water regimes under the different cropping systems at the end of the growing season reflect different water use patterns by the cropping systems and management. Precipitation during the growing season for June and July was aproximately twice the normal (136 and 131 mm, respectively), and half of the normal for August (33 mm) (Appendix 8.2). The CL cropping system used water for a longer period of time, resulting in significantly lower water in the profile than the other cropping systems. The extensive root studies of Weaver (1926) showed that the roots of various crops plants differ widely in their inherent capacity to penetrate the soil. Crops like alfalfa have been shown to grow roots to depths of more than 10 m when soil conditions are favourable. The CL cropping system had been reseeded in early June and had not been harvested by soil sampling time. The amount of water in the profile of the CB cropping system was the greatest, indicating that either more water had penetrated this soil profile or this cropping system used less water. Water use by barley occurred over a much shorter period as it was seeded in early June (8th) and by September (19th) it was mature and harvested. The lowest amounts of soil water in the lower portion of the profile were observed in the CG cropping system. Grass roots thoroughly permeate the soil and consequently remove available water from the fine interstices of the soil (Richards and Wadleigh 1952). The many fine roots would intercept and extract soil water continuously over the whole growing season compared to an annual crop such as barley which has to develop a new root system annually.

3.3.3 Saturated Hydraulic Conductivity

Saturated hydraulic conductivity (K sat) was determined for each of the cropping systems at three depths and their standard deviations and logarithmic values were calculated (Table 3.3). The only significant difference observed for the untransformed data was the change in K sat due to depth ($P \leq 0.0062$). Analysis of variance of the data was also conducted on the transformed data because the standard deviations were of the same magnitude as the means and the most effective transformation for this situation is a log transformation (Little and Hills 1978). The transformed data ($\log_{10}$) indicated that there were significant differences between cropping system ($P \leq 0.0009$) and depth ($P \leq 0.0001$). There was no significant interaction between soil and depth.

The surface horizon (0-15 cm) of the CG cropping system had the highest K sat (6.82 cm h^{-1}). The 15-30 cm depth interval of the CG and CL cropping systems had K sat values in the 10^{-2} cm h^{-1} range. For the 30-45 cm depth interval the CL cropping system had the highest K sat (2.18×10^{-2} cm h^{-1}) while all other cropping systems had values in the range of 10^{-4} cm h^{-1}. For the 15-30 cm depth interval, the soil from the CB cropping system had a K sat of 4.50×10^{-4} cm h^{-1}, while all other cropping systems had K sat that were considerably greater. The overall mean K sat for the three depths of the CL cropping system were significantly higher than those of the other cropping systems ($P \leq 0.05$).

The mean K sat decreased with depth and all three depths were significantly different from each other ($P \leq 0.05$). The average K sat values calculated from the antilogs of the means of the $\log_{10}$ transformed data, were 1.55, 4.81×10^{-3} and 4.37×10^{-4} cm h^{-1} for 0-15, 15-30 and 30-45 cm depth intervals, respectively.

Saturated hydraulic conductivity decreased with depth, reflecting the profile characteristics of a Luvisol. Saturated hydraulic conductivity is not only influenced by texture of the soil but also by structure, and both of these variables change with depth. The conductivity also depends on the size of the pores and not just on total porosity (Hillel 1971). Root channels, worm holes and large cracks can contribute greatly to the magnitude of the flux. Improved soil

Table 3.3 Saturated hydraulic conductivity of soils for the five cropping systems for three depth intervals.

Depth Interval (cm)	Cropping System				
	CB[1]	Bf	Fb	CG	CL
			Mean ($\mathrm{cm\ h^{-1}}$)		
0-15	0.96	2.14	1.85	6.82	1.85
15-30	$4.50\text{x}10^{-4}$	$5.01\text{x}10^{-3}$	$4.41\text{x}10^{-3}$	$1.20\text{x}10^{-2}$	$6.14\text{x}10^{-2}$
30-45	$7.31\text{x}10^{-4}$	$2.73\text{x}10^{-4}$	$1.44\text{x}10^{-4}$	$6.42\text{x}10^{-4}$	$2.18\text{x}10^{-2}$
Mean	0.62	2.28	0.73	0.32	0.64
			standard deviation ($\mathrm{cm\ h^{-1}}$)		
0-15	0.32	1.41	2.56	8.59	0.50
15-30	$2.48\text{x}10^{-4}$	$8.00\text{x}10^{-2}$	$4.69\text{x}10^{-3}$	$1.25\text{x}10^{-2}$	$1.57\text{x}10^{-2}$
30-45	$5.68\text{x}10^{-4}$	$2.29\text{x}10^{-4}$	$1.40\text{x}10^{-4}$	$9.33\text{x}10^{-4}$	$2.51\text{x}10^{-2}$
Mean	0.11	0.50	0.85	2.87	0.18
			Mean ($\log_{10}\ \mathrm{cm\ h^{-1}}$)		
0-15	-0.038	0.244	-0.090	0.584	0.255
15-30	-3.406	-1.899	-2.577	-2.488	-1.221
30-45	-3.212	-3.751	-3.972	-3.625	-2.241
Mean	-2.219 B[2]	-1.802 B	-2.213 B	-1.843 B	-1.069A

		Analysis of Variance Saturated hydraulic conductivity			
		actual		$\log_{10}$	
Source of Variation	df	Mean Square	Pr.>F[3]	Mean Square	Pr>F[3]
Rep	2	3.75	0.5188	1.40	0.0673
Cropping System(CS)	4	5.41	0.5006	1.97	0.0009
Error a	8	5.93		0.13	
Depth(D)	2	36.59	0.0062	49.97	0.0001
CS*D	8	5.46	0.4751	0.82	0.1330
Error b	20	5.53		0.45	

[1] see Table 3.1.

[2] means followed by different letter are significantly different at $P \leq 0.05$,

[3] the significance probability associated with the F statistic.

structure as a result of the different cropping systems can increase the K sat as evidenced by the results observed in the 15-30 cm depth interval of the CG cropping system and the 15-30 and 30-45 cm depth interval of the CL cropping system when compared to cropping systems with frequent cultivation. The low K sat of the 15-30 cm depth interval in the CB cropping system showed the detrimental effects of annual cultivation and exclusion of forage crops from this cropping system.

3.3.4 Soil Water Retention

Soil water retention at 0.03, 0.1, 0.5 and 1.5 MPa and plant available water for each of six depth intervals and five cropping systems were determined (Table 3.4).

Soil water retention was greatest for the 30-45 cm depth interval for each cropping system. For this depth interval soil water retention at 0.03 MPa was 36.5 % and 21.3 % at a tension of 1.5 MPa. At the highest tension (1.5 MPa), the 15-30 cm depth interval retained the greatest amount of soil water due to the higher clay content. Significant differences were observed between cropping systems ($P \leq 0.0147$) and depth ($P \leq 0.0001$) at all four tensions.

Water retention of the surface horizon of the CG cropping system was the highest at all four tensions. The overall average water retention for the CG cropping system was the greatest at all tensions, except 1.5 MPa, likely due to higher organic matter levels. At 1.5 MPa. the water retention capacity of the CB cropping system was equal to that of the CG and Fb cropping systems.

The soil water retention curve is strongly affected by soil texture. The greater the clay content of the soil, the greater is the water content at any particular tension and the more gradual the slope

Table 3.4 Soil water retention and plant available water for each of the cropping systems and six depths and the ANOVA table.

Depth Interval cm	Suction in MPa 0.03	0.1	0.5	1.5	Available water[1] holding capacity
	$g\ 100\ g^{-1}$				cm depth $increment^{-1}$
			CB[2] Cropping System		
0-15	31.8	25.3	18.0	14.2	2.9
15-30	34.9	29.3	22.8	19.9	2.6
30-45	38.4	32.3	25.5	22.8	3.2
45-60	34.3	29.3	23.3	20.7	2.7
60-90	31.4	26.7	21.6	20.3	4.8
90+	30.5	26.4	21.5	19.7	
profile					16.2 A[3]
			Bf Cropping System		
0-15	30.7	24.7	17.2	13.9	2.9
15-30	31.4	26.5	20.2	18.8	2.1
30-45	36.6	30.4	22.6	21.4	3.5
45-60	34.2	29.3	22.4	20.8	3.1
60-90	30.1	23.9	19.5	19.7	5.0
90+	27.5	22.8	18.9	18.3	
profile					16.6 A
			Fb Cropping System		
0-15	30.9	25.0	18.1	14.3	2.6
15-30	34.4	29.3	22.2	19.3	2.5
30-45	35.7	30.0	23.8	20.2	3.5
45-60	33.5	27.8	21.7	19.8	3.2
60-90	31.9	26.9	21.1	20.4	5.0
90+	27.4	22.8	18.7	16.7	
profile					16.9 A
			CG Cropping System		
0-15	34.9	27.4	19.4	16.3	3.3
15-30	32.6	27.4	22.0	20.2	2.1
30-45	36.5	30.6	23.4	21.6	3.2
45-60	34.6	29.2	23.1	20.8	3.0
60-90	32.1	26.9	21.1	20.1	5.1
90+	29.8	24.7	19.1	18.6	
profile					16.6 A
			CL Cropping System		
0-15	30.5	24.8	18.3	13.9	2.5
15-30	28.5	23.7	17.5	16.4	1.9
30-45	35.7	30.1	22.9	20.7	3.2
45-60	33.7	28.5	21.7	20.5	2.9
60-90	30.6	25.5	21.4	19.3	4.9
90+	27.9	23.2	20.7	18.4	
profile					15.4 A

[1] Available water holding capacity calculated from difference between soil water at 0.03 and 1.5 MPa on volume-basis ($cm^3\ cm^{-3}$) and multiplying by bulk densities from Table 3.1.

[2] see Table 3.1.

[3] Profile available water holding capacity for 0-90 cm depth, means followed by different letters are significantly different at $P \le 0.05$.

Table 3.4 Continued.

	Analysis of Variance					
	Soil Water Retention			AWHC[4]		
Source of Variation	df	Mean Square	Pr.>F[5]	df	Mean Square	Pr.>F[5]
Rep	3	15.19	0.3805	3	1.20	0.0020
Cropping System(CS)	4	65.84	0.0147	4	0.27	0.5732
Error a	12	13.59		12	0.36	
Tension(T)	3	4488.88	0.0001	NA[6]		
CS*T	12	2.30	NS	NA		
Error b	45	2.19		NA		
Depth(D)	5	15.80	0.0001	4	3.02	0.0001
T*D	15	26.44	0.0001	16	0.27	0.0589
CS*T*D	60	0.94	1.0000	NA		
Error c	300	3.22		60	0.16	

[4] AWHC-available water holding capacity on volume-basis.
[5] The significance probability associated with the F statistic.
[6] NA is not applicable.

of the curve. This relationship was apparent in the soils from each cropping system with the Bt horizon (30-45 and 45-60 cm depth intervals approximately) having a greater water content at any particular tension. The surface and lower horizons of each cropping system held lesser amounts of soil water at any particular tension indicating a coarser texture. The higher water retention of the surface horizon of the CG cropping system is a result of its higher organic matter content (3.6 %) compared to the other cropping systems (3.4, 3.2, 2.8 and 2.7 % for the CL, Bf, CB and Fb cropping systems, respectively) (Appendix 8.6).

Profile available water holding capacity was not significantly different among the cropping systems when expressed on a volume-basis (Table 3.4). The average available water holding capacity was significantly different for each depth interval except 0-15 and 45-60 cm intervals. The 15-30 cm depth interval had the lowest (2.23 cm available water per depth increment) while the 30-45 cm depth interval had the greatest (3.22) available water holding capacity. The 0-15, 45-60 and 60-90 cm depth intervals had values between the two extremes (2.87, 2.93 and 5.10 cm, respectively). The 60-90 cm depth interval had a value twice those of the other depth increments.

3.3.5 Infiltration Rates and Accumulated Water

Soil moisture for the surface horizon (0-15 cm) at time of the determining infiltration measurements was 22.1, 20.7, 21.6, 24.8 and 18.3 % for the CB, Bf, Fb, CG and CL cropping systems, respectively. Infiltration rates, determined over 480 min are plotted (Figure 3.1) and the ANOVA of rates at specific times are shown (table 3.5). Assuming the infiltration rate at 10 min to be 100 % then the infiltration rate by 30 min decreased to approximately 50 %. By 480 min, the rate of infiltration had decreased further to about 10 % for all the cropping systems except CG. The 10 min rates ranged from a low of 9.2 mm h^{-1} for the Fb cropping system to a high of 19.3 mm h^{-1} for the CL cropping system. Higher initial rates of infiltration for the CB and Bf cropping systems could be attributed to surface cracking. The expected decreasing order of infiltration rate for the cropping systems (namely CG > CL > Fb > Bf > CB) was not observed at 10 min, but was over a longer time period (480 min). At 30 min, the highest infiltration rates were observed for the CL and CG cropping systems (9.7 and 9.4 mm h^{-1}). At 480 min the rate of infiltration was the greatest for the CG cropping system (2.5 mm h^{-1}). The CL cropping system had an infiltration rate of 1.8 mm h^{-1} at 480 min while the remaining cropping systems had infiltration rates of 1.4 mm h^{-1} or less.

One method of quantifying differences in the rate of infiltration is

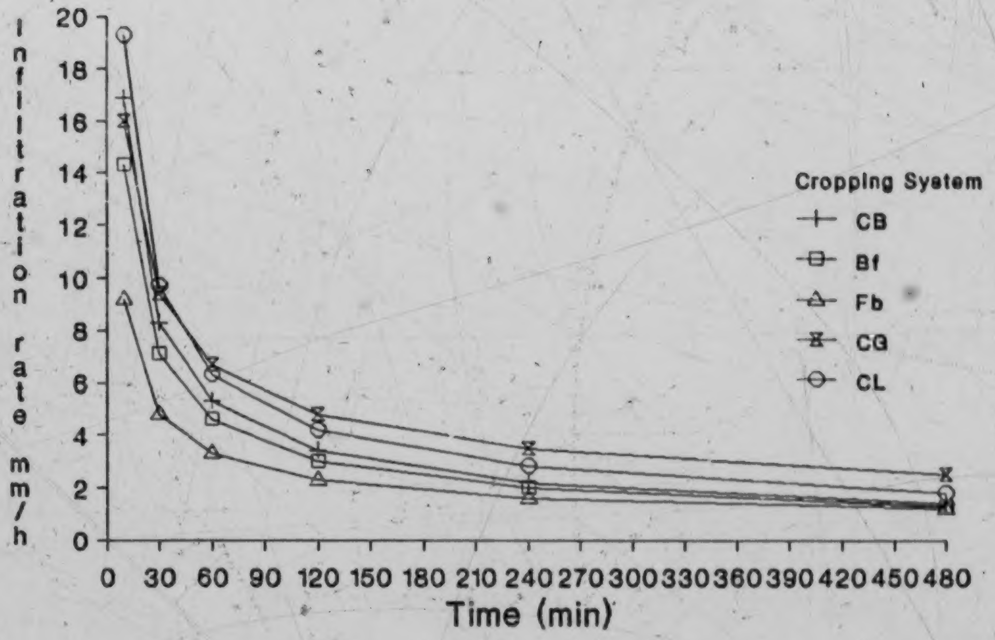

Figure 3.1. Infiltration rates for the five cropping systems over a period of 480 min.

Table 3.5 Analysis of variance for the infiltration rate over time (min) for each cropping system.

Source of Variation	df	Analysis of Variance mean square	Pr.>F[1]
Rep	3	34.03	0.0004
Time(T)	5	500.73	0.0001
Error a	15	2.99	
Cropping System(CS)	4	52.58	0.0024
T*CS	20	7.11	
Error b	72	11.47	

[1] the significance probability associated with the F statistic.

infiltration rate because of the rapid decrease in the infiltration rate at the outset. The infiltration rate ratio at 30 to 480 min was a better ratio to use than the 10 to 480 min ratio because by 30 min the infiltration rate had stabilized to reflect the cropping system differences and not surface soil characteristics. The lowest ratios (30 to 480 min) were observed for the CG cropping system (4.0) and this was followed by the CL cropping system (5.6). The Fb, Bf and CB cropping system ratios were considerably higher (6.4, 6.5 and 7.0, respectively). The CB cropping system had the highest ratio indicating the greatest change in infiltration rates over the 480 min period with 15.4 and 7.0 for the 10 to 480 min and 30 to 480 min periods, respectively. A drastic change in infiltration rates is an indication of an unstable structure of soils due to disaggregation according to Mazaruk et al. (1955).

Total amounts of water accumulated at 10 min were highest for the CB and CL cropping systems (Fig. 3.2, Table 3.6). After 480 min of infiltration however, the total amount of water accumulated was greatest for the CG cropping system (38.2 mm). This was followed by the CL cropping system (32.3 mm). The CB, BF and Fb cropping systems to consider changes between infiltration rates at two specific times. The two ratios that were used to assess these changes were the 10 to 480 min and the 30 to 480 min infiltration rates (Table 3.7). The ratio for 10 to 480 min was considerably greater than the 30 to 480 min accumulated 27.3, 24.0 and 18.1 mm, respectively. The CG and CL cropping systems accumulated the greatest amount of water because of more stable structures and therefore greater infiltration rates. The CB, Bf and Fb cropping systems were cultivated more frequently and also have less organic matter. The lowest ratios were observed for the CG cropping system. A significant difference ($P \leq 0.05$) was observed for the 30 to 480 min ratio, with the CG cropping system being significantly different from Fb cropping system (Table 3.7).

Thus, cropping system affected the infiltration rates of the soils. Increasing the content of decomposed and partially decomposed organic residues substantially increases infiltration into most soils (Wischmeier and Mannering 1965). Other important factors include the amount of plant residues on the surface, root channels, earthworm activity, the nature and rate of the water applied and nature and condition of the soil.

The wide range in initial infiltration rates was a reflection of the surface of the different cropping systems not being prepared in the same manner. Wischmeier and Mannering (1965) eliminated some of the soil surface differences by determining infiltration rates only on fallowed plots to determine the effects of cropping systems in relation to soil properties. The surface of the CL and CB cropping systems had the greatest amount of soil cracking while the CG cropping system only had very few minor surface cracks. In this study it was not until the 30 min mark that the trends of higher infiltration rates for the CG and CL cropping systems became apparent. At 480 min the CG and CL cropping system had the highest infiltration rates (2.5 and 1.8 mm hr^{-1}, respectively) while the three remaining cropping systems (CB, Bf and Fb), which had more frequent tillage operations, all had infiltration rates of 1.4 mm h^{-1} or less. Mazurak et al. (1955) also observed that continuous cropping (row crops) had a deleterious effect on soil structure and the rate of water entry into the soil. In their study,

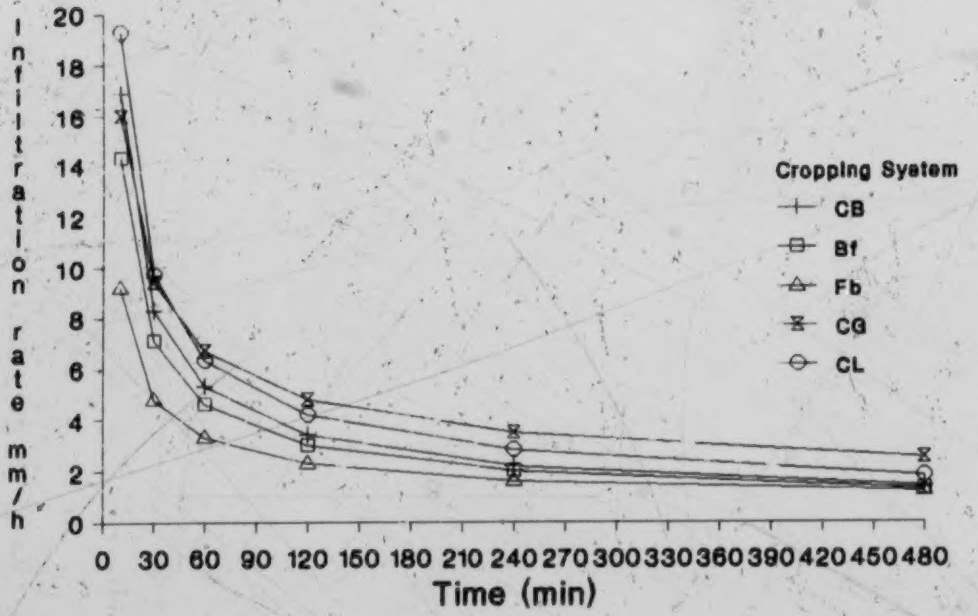

Figure 3.2. Accumulated water (mm) for the five cropping systems over a period of 480 min.

Table 3.6 Analysis of variance for the accumulation of water (mm) for the five cropping systems over a period of 480 min.

		Analysis of Variance	
Source of Variation	df	mean square	Pr.>F[1]
Rep	3	172.43	0.0090
Time(T)	5	1600.25	0.0001
Error a	15	30.89	
Cropping System(CS)	4	272.72	0.0006
T*CS	20	29.03	0.9063
Error b	72	49.08	

[1] the significance probability associated the F statistic.

Table 3.7 Water infiltration rate (mm h^{-1}) and accumulated water (mm) ratios for time 10 to 480 and 30 to 480 min for each cropping system.

Cropping System	Water Infiltration Rate 10/480	Water Infiltration Rate 30/480	Accumulated Water 10/480	Accumulated Water 30/480
	ratio			
CB[1]	15.4	7.0	0.17	0.28
Bf	13.9	6.4	0.18	0.29
Fb	14.1	6.4	0.19	0.30
CG	7.0	4.0	0.10	0.20
CL	11.6	5.6	0.16	0.27
Significance Level	0.5397	0.4922	0.2184	0.0557

[1] see Table 3.1.

maximum amounts of water entry after two hours of irrigation were obtained in the continuous alfalfa plots. The CG cropping system in this study had higher infiltration rates because it was reseeded less frequently (therefore less cultivation) and it had a more stable surface structure due to sod formation. These same trends are also observed for the accumulated depth of water over time for each cropping system.

Mazurak et al. (1955) used the ratio of the 10 to 120 min water intake rates as a measure of the water-stability of aggregates. The 10 to 480 min ratios of 7.0, 11.6, 13.9, 14.1 and 15.4 would indicate decreasing water-stable aggregates for the CG, CL, Bf, Fb and CB cropping systems, respectively, based on their conclusions. Cropping systems with the most stable structures had the highest infiltration rates at 480 min.

3.4 SUMMARY AND CONCLUSIONS

Soil properties differ under different cropping systems. Soil water profiles of the cropping systems after 16 years were different because crops utilized water from the profile at different rates and the cropping systems were managed differently. For the year of sampling (1983) precipitation was much above normal for June and July and below normal for August. The CL cropping system had the lowest amount of soil water in the profile in September while the CB cropping system had the most soil water. This was due to the barley being mature at time of sampling while the red clover of the CL cropping system was still actively growing.

The of K sat soil was improved by growing forage crops but this was crop dependent. The CG and CL cropping systems had higher K sat for the 15-30 cm depth interval while the CL cropping system also had a higher K sat for the 30-45 cm depth interval.

Soil water retention under the different cropping systems was quite similar. Only the surface horizon of the CG cropping system had a higher water retention at all tensions compared to the other cropping systems. The available water holding capacity of the surface horizon was also highest in the CG cropping system. The greatest available water holding capacity was generally found for the 30-45 and 45-60 cm depth intervals which corresponded to the clay accumulation in the Bt horizon.

The infiltration rates and the depth of accumulated water over time reflected cropping practices. The CG cropping system, which had the fewest cultural operations and highest organic C, also had the highest infiltration rate. The CG cropping system soil with its stable surface horizon of sod did not disaggregate during the application of water. The other continuous forage cropping system, CL, had the second highest infiltration rate. This cropping system had considerably more cultural operations over 16 years because this crop was reseeded on a more regular basis and its surface cover was not as extensive as that of the CG cropping system. Cropping systems with regular cultural activities and no perennial crops had lower infiltration rates than those of the CG and CL cropping systems. The ratio of the infiltration rate at the beginning and the end of the infiltration period indicated decreasing soil structural stability in the order of: CG > CL > Bf > Fb > CB cropping systems.

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CHAPTER 4

The Effects of Diverse Cropping Systems on Aggregation of a Luvisolic Soil in the Peace River Region

4.1 INTRODUCTION

Soil structure is defined as the natural arrangement of soil primary particles into aggregates or peds. Marshall (1962) defines soil structure as the arrangement of soil particles and the pore space between them. The binding of soil particles into stable aggregates is essential for optimum soil tilth. Soil tilth is an important physical condition of the soil as it relates to its ease of tillage, its fitness as a seed bed and its resistance to seedling emergence and root penetration (Agriculture Canada 1976). Soil structure and tilth are difficult to measure quantitatively because no one measurement adequately characterizes these parameters completely.

Cultivation tends to reduce aggregation of soils while continuous cover crops improve soil structure (Low 1972). Soils in the field that are subjected to frequent and intense cultivation undergo deterioration of their structure which is shown by a decrease in the stability and average size of aggregates (Greacen 1958, Clarke et al. 1967). Rovira and Greacen (1957) suggested that the physical disruption of aggregates exposes organic matter that was not previously accessible to microbial attack and indirectly results in decreased stability of the aggregates.

The mechanism of soil aggregation has been reviewed by Emerson (1959), Harris et al. (1966) and Allison (1969). Aggregate stability increases with increasing clay content (Kemper and Koch 1966, Bergsma and Valenzuala 1981, Wustamidin and Douglas 1985) and organic matter (Harris et al. 1966, Lynch and Bragg 1985, Burns and Davies 1986).

Chepil (1955) found that the percentage of aggregates greater than 0.84 mm increased linearly with increasing amounts of clay over 20 %. The soils used were artifically made with different proportions of sand and clay. Kemper and Koch (1966) found a similar relationship for aggregate stability and clay content. The type of clay also affects aggregation and aggregate stability. Smectite clays form aggregates more readily but slake more easily than kaolinites (Mazurak 1950, Robinson and Page 1950).

Not only the addition of organic matter but also its decomposition results in the aggregation of soil particles (Harris et al. 1966, Burns and Davies 1986). Decomposition is a continuing process and the type and amounts of organic matter additions and factors influencing micro-organisms all are important determinants of aggregation. Harris et al. (1966) and Burns and Davies (1986) reviewed the effects of crop rotations and crop type on soil aggregation. The largest and most stable aggregates occur under continuous perennial crops such as grass (Low 1972). Aggregation and aggregate stability generally decrease with decreasing frequency of perennial crops in a rotation and/or the increasing amount of cultivation or fallow (Harris et al. 1966, Dormaar and Pittman 1980, Lynch and Bragg 1985, Baldock and Kay 1987).

Polysaccharides play an important role in the formation of aggregates (Burns and Davies, 1986); aggregate stability was positively correlated with polysaccharide levels as determined by removal with periodate. Larger aggregates were generally unaffected by the periodate treatment indicating that the polysaccharide binding mechanism was not as prevalent in large aggregates. The importance of high molecular weight polysaccharides in maintaining aggregate stability has been shown

(Acton et al. 1963, Swincer et al. 1968). Good tilth developed under continuous forage production has been attributed to the continuous supply of new decomposable organic matter and micro-organism activity. Tisdall et al. (1978) showed that soil sterilization or dryness increased the effect of physical disruption because micro-organisms that produce bonding substances were destroyed.

The effect of cultivation on deterioration of soil structure as compared to virgin soils, and the effects of cropping systems with less cultivation improving soil structure have been reported by numerous researchers (Toogood and Lynch 1959, Low 1972, Aina 1979, Martel and McKenzie 1980). These studies showed that cultivation reduced nitrogen, carbon and aggregate stability. Generally virgin grassland soils have a higher percentage of macro-aggregates while cultivated soils contain a greater percentage of micro-aggregates (Tisdall and Oades 1980, Oades 1984). Aggregation decreased rapidly when soils were continuously row cropped following sod or hay crops and increased when a grass was part of the rotation (Low 1972). Toogood and Lynch (1959) observed that the mean weight-diameter of water-stable aggregates of a Luvisolic soil at Breton were nearly double in soils from a five year rotation of grains (3 years) and grass-legume (2 years) compared to a wheat-fallow sequence. Any increased aggregation of Luvisolic soils is beneficial because of their major physical problems as they puddle easily, pack hard after wetting and quickly form a hard crust after a rain (Bentley et al. 1971, Robertson and McGill 1983).

The purpose of this study was to compare diverse cropping systems on a Luvisolic soil in the Peace River region of Alberta as to: i)aggregate distribution by dry and wet sieving, ii)aggregate stability by wet sieving, the McCalla water drop method and dispersion/slaking test, and iii)carbohydrate content of aggregates.

4.2 MATERIALS AND METHODS

4.2.1 Site and Soils

Surface bulk samples were collected in the early fall of 1986 from the Beaverlodge Long-term Cropping System Field Experiment located approximately six km east of the Beaverlodge Research Station in the Peace River Block of Alberta in the early fall of 1986. The plots were arranged in a randomized block design with each of the five cropping systems being replicated four times, each plot measuring 22 by 58 m. The experimental plot area was established in 1968 on a Luvisolic soil. The site and its management history from 1968 to present has been described in detail in Chapter 2.

The cropping systems consisted of:

1)continuous barley (CB),
2a)barley/forage (Bf) (3 yr of barley followed by 3 yr of forage),
2b)forage/barley (Fb) (3 yr of forage followed by 3 yr of barley),
3)continuous grass (CG) and
4)continuous legume (CL).

Barley (Hordeum vulgare L., cv 'Galt') from the CB and Bf cropping systems was harvested as grain with the straw left on the field. The forage component of the Fb and Bf cropping systems was a mixture of bromegrass (Bromus inermis L., cv 'Carlton') and red clover (Trifolium pratense L., cv 'Norlac'). The CG cropping system was planted to continuous bromegrass and the CL cropping system to red clover. Originally alfalfa (Medicago sativa L., cv 'Beaver') was used as the legume for the CL abd Fb cropping systems but since 1978 red clover was planted. All forages were harvested as hay.

The CB cropping system was cultivated annually (disked, harrowed, etc.) to establish a new crop of barley. The Bf and Fb were cultivated annually during the periods when growing barley (three years) and when new forage crops were established. Newly established forage crops were generally not underseeded with barley. The CL cropping system had more frequent cultivation compared to the CG cropping system because it had to be reseeded more often. The CL cropping system was subjected to an additional period of summerfallow and increased cultivation during 1975-78 when it was plowed (July 1975), reseeded in the spring of 1976, plowed again at the end of July, fallowed during 1977 and reseeded in the spring of 1978 (chapter 2).

Soil samples were collected from the 0-15 cm depth interval using a square nosed-shovel. Ten random locations throughout each plot were sampled and bulked. Samples were handled carefully to preserve structure. Samples were spread out to air-dry on large sheets of paper. Near air-dry samples were subjected to gentle sieving through an 12.5-mm sieve. Air-dry samples were stored in plastic bags but not stacked to prevent the crushing of aggregates.

4.2.2 Dry Sieving

Dry sieving was accomplished with a rotary cylinder of nested sieves, constructed according to Chepil (1962) and operated as reported by Metting and Rayburn (1983). A sample of approximately 400 g was fed into the nested sieves by means of a conveyor belt at a speed of 100 mm min^{-1}. The cylinders turned slowly (12 rpm) until the whole sample was segregated into aggregates measuring 38.1-12.7, 12.7-6.4, 6.4-2.4, 2.4-0.84, 0.84-0.42 and <0.42 mm. All dry-sieving was done in duplicate and the resulting separates were collected, weighed, and saved in small boxes to prevent crushing. The fraction (%) collected from each sieve was calculated on an air-dry basis of the whole soil sample.

4.2.3 Wet Sieving

The procedure and apparatus used for wet sieving were those of Yoder (1936). The apparatus consisted of three metal cylinders, into each of which was suspended on a rocker arm a stack of six sieves (18 cm diameter) with 4, 2, 1.0, 0.5, 0.25 and 0.125 mm openings. The arm was driven by an electric motor and pivoted up and down with a 4 cm stroke at 30 cycles per minute for 10 min. Water in the cylinders was at room temperature (20+2°C) and was kept at a depth sufficient to cover the top sieve at the bottom of stroke. Samples for wet sieving consisted of 40 g of oven-dry equivalent soil or aggregates. Samples were evenly spread over the top sieve at the start of the operation, and determinations were duplicated.

The wet sieving apparatus was used for total aggregate distribution of the soils as well as the determination of aggregate stability for selected aggregate fractions collected from the dry seiving procedure. Aggregate distributions were determined for the fractions collected on each sieve and calculated after oven drying at 105°C in a forced air oven. Aggregate stability of selected aggregates from dry sieving was also determined using the same wet sieving apparatus by using only the sieves smaller than the aggregate fraction being evaluated. The sieves with larger screen openings than the aggregates being assessed were put at the bottom of the stacked sieves so that the same number of sieves and water levels could be used. The amount of aggregates retained on each sieve was expressed as a portion (%) of the whole soil on an oven dry basis. The aggregate fraction less than 0.125 mm was determined from the difference between the original total sample and fractions retained on the sieves.

4.2.4 Aggregate Mean Weight Diameter

The aggregate mean weight diameter (MWD) was calculated from the average of two sub-samples for each of the dry sieving and wet sieving aggregate distributions and for the wet aggregate stability determined for aggregates from the dry sieving procedure. MWD, as defined by Van Bavel (1949), was calculated following the method described by Kemper and Chepil (1965). The MWD was calculated as the sum of the products of the mean diameter (x_i) of each size fraction and the proportion of the sample weight (w_i) occurring in that size fraction as expressed by:

$$MWD = \sum_{i=1}^{n} x_i w_i$$

4.2.5 Waterdrop Method for Aggregate Stability

Aggregates approximately 0.20 ± 0.03 g in weight were selected at random from aggregates separated by the rotary dry sieves. Ten aggregates were selected from each plot for a total of 40 samples per cropping system (4 replicates). The waterdrop apparatus consisted of a constant head apparatus made from a 500 ml separatory funnel which delivered distilled water in 4.7 mm drops from a disposable pipette tip at one drop per 4.5 s from a height of 0.3 m (McCalla 1940). The water was at kept room temperature (21 ± 1°C). The number of drops required to disintegrate the aggregate enough to pass through a 1-mm screen was calculated from the time in seconds from the first drop to complete dispersion.

4.2.6 Dispersion/Slaking Test for Aggregate Stability

A simple method to measure aggregate stability was developed by McQueen (1982 personal communication, Appendix 8.9) because most methods are difficult to use outside the laboratory. Six aggregates 3-6 mm in size are subjected to disruptive forces by inverting them in 10 ml of water in common test tubes and comparing to prepared standards. The slaking standard is prepared by the complete crushing of and dispersion of three aggregates in 40 ml of water. The number of inversions required to obtain similar turbidity of the sample and standard after 15 s of settling is the slaking index. The dispersion standard is prepared by cutting three aggregates in half (no water added) and the number of inversions required for all the test aggregates to be no larger than the divided aggregates of the standard is recorded as the dispersion index. The slaking and dispersion indexes for each sample can be plotted to obtain a comparison of the samples. A more complete procedure and flowchart is presented in detail in the Appendix 8.9.

4.2.7 Carbohydrate Content of Aggregates

Soil carbohydrates of four of the six size fractions (12.7-6.4, 6.4-2.4, 2.4-0.84 and 0.84-0.42 mm) from dry sieving were determined by the colorimetric method of Dubois et al. (1956). The carbohydrates in the aggregates were hydrolyzed using sufficient H_2SO_4 to give a solution equivalent to 100 ml of 3 N H_2SO_4. The hydrolysate was analyzed using the phenol-sulfuric acid method (Dubois et al. 1956).

4.2.8 Statistical Analyses

The data were subjected to analyses of variance (ANOVA) using a randomized block design with each block replicated four times (Agriculture Canada 1984). Replicate analyses of samples, duplicates for dry sieving, were treated as subsamples and the main effect and interactions of this factor were pooled and included in the ANOVA as "Subsample Error". The means of the main treatment effects were subjected to multiple comparison procedures using the Duncan's New Multiple Range test. A protected Duncan's test was used, meaning that no significant difference of the main treatment means was declared unless the F ratio was significant ($P<0.05$).

4.3 RESULTS

4.3.1 Dry Sieving Aggregate Distribution for Whole Soil

The dry sieving aggregate distribution for the whole soil for aggregate sizes from less than 0.42 to 38.1 mm in six increments were determine (Table 4.1). The greatest proportion of aggregates in the less than 0.42 mm aggregate fraction was in the CL cropping system (27.6 %) while the other four cropping systems had less than 20 %. Similarly, in the 0.42-0.84 mm fraction, the CL cropping system had a significantly higher proportion of aggregates (18.2 %) compared to less than 15 % for the CB, Bf, Fb and CG cropping systems. Thus the amount of wind erodible soil (<0.84 mm) was much greater for the CL cropping system (45.8 %) compared to the other cropping systems with 32.7, 32.0, 34.4 and 30.6 % for the CB, Bf, Fb and CG cropping systems, respectively. The highest proportion of aggregates in the 0.84-2.4 mm fraction was also found in the CL cropping system although the levels were not significantly different from the CG, Bf and CB cropping systems. The proportion of the 0.84-2.4 mm fraction found in the Fb cropping system was significantly lower than that from the CL cropping system but not from the other cropping systems. In the 2.4-6.4 mm fraction, significant differences were only observed between the CG and CL cropping systems. The 6.4-12.7 mm aggregate fraction of the CL cropping system (10.4 %) was significantly smaller than those of the other four cropping systems (16.5-18.0 %). In the largest aggregate fraction (12.7-38.1 mm), the amounts from any cropping system were small, less than 4.1 %, and no significant differences among cropping systems were observed.

The MWD for the CL cropping system was significantly smaller than the other cropping systems ($P \leq 0.05$), a result of the larger amount of the aggregates being of the smaller aggregate size fractions. Differences among the CB, Bf, Fb and CG cropping systems were not significant.

4.3.2 Wet Sieving Aggregate Distribution of Whole Soil

There were significant differences among cropping systems in the distribution of aggregates from wet seiving (Table 4.2). The amount of material passing through the 0.125-mm sieve ranged from 11.2 to 18.3 % but the differences were not significant. The aggregates retained on the 0.125-mm sieve were significantly different, with the CG cropping system retaining only 4.9 % of the soil mass compared to the other cropping systems which had between 10.5 and 13.0 % in this fraction. In both the 0.25-0.5 and 0.5-1.0 mm aggregate sizes, the same significant trend was observed. The greatest amounts of aggregates in these fractions were observed in the CL cropping system (19.9 and 19.1 %), but this was not significantly different from the CB, Bf or Fb cropping systems. The smallest amounts of aggregates in these two aggregate size fractions (0.25-0.5 and 0.5-1.0 mm) were found in the CG cropping system (8.2 and 11.9 %, respectively). The amount of aggregates retained on

Table 4.1 Aggregate distribution as measured by the Chepil rotary sieve.

Aggregate size mm	Cropping System (%)					Significant level
	CB[1]	Bf	Fb	CG	CL	
12.7 -38.1	3.2	4.1	2.4	2.8	1.6	ns[3]
6.4 -12.7	17.5 a	18.0 a	18.0 a	16.5 a	10.4 b[2]	**
2.4 - 6.4	34.7 ab	34.4 ab	34.0 ab	37.9 a	29.0 b	*
0.84- 2.4	11.8 ab	11.6 ab	11.3 b	12.2 ab	13.2 a	*
0.42- 0.84	14.8 b	14.1 b	14.5 b	13.0 b	18.2 a	**
<0.42	17.9 b	17.9 b	19.8 b	17.6 b	27.6 a	**
	mm					
MWD	4.3 a	4.6 a	4.1 a	4.3 a	3.1 b	**

[1] CB continuous barley, Bf barley/forage, Fb forage/barley, CG continuous grass and CL continuous legume.

[2] same lowercase letters in row indicate no significant difference between cropping systems ($P \leq 0.05$).

[3] significant levels: ** ≤0.01, * ≤ 0.05 and ns was not significant at ≤0.05.

Table 4.2 Aggregate distribution as measured by the wet sieving technique of Yoder (1939) using a set of six nested sieves.

Aggregate size mm	Cropping System (%)					Significant level
	CB[1]	Bf	Fb	CG	CL	
>4.0	12.5 b	15.8 b	16.4 b	33.0 a	15.5 b[2]	**[3]
2.0 -4.0	9.1 b	10.9 b	9.3 b	16.5 a	8.8 b	**
1.0 -2.0	13.0	13.5	10.9	14.3	13.9	ns
0.5 -1.0	17.7 a	16.4 a	15.8 a	11.9 b	19.1 a	**
0.25 -0.5	17.1 a	16.4 a	17.8 a	8.2 b	19.9 a	**
0.125-0.25	12.3 a	10.8 a	13.0 a	4.9 b	10.5 a	**
<0.125	18.3	16.2	16.8	11.2	12.3	ns
	mm					
MWD	1.5 b	1.7 b	1.7 b	2.8 a	1.6 b	**

[1] see table 4.1

[2] Same lowercase letters in a row indictes no significant differences between cropping systems.

[3] significant levels: ** ≤0.01, * < 0.05 and ns is not significant at ≤0.05.

the 1-mm sieve was not significantly different among the cropping systems with a range of 10.9 to 14.3 %. For the 2-4 mm aggregate size fraction, the CG cropping system had the greatest proportion of aggregates with 16.5 % being retained on the 2-mm sieve. This was significantly higher than the four other cropping systems. A similar trend was observed for aggregates greater than 4-mm, the CG cropping system had 33.0 % of its total soil retained in this size fraction. The mass of aggregates in this same size fraction for the other cropping systems amounted to less than 16.4 % (not significantly different from each other).

The MWD for the wet aggregate distribution was significantly larger for the CG cropping system compared to those of the other four cropping systems.

4.3.3 Aggregate Stability by Wet Sieving

The aggregates of 6.4-12.7, 2.4-6.4 and 0.84-2.4 mm size ranges separated with the Chepil rotary sieve from each cropping system were wet sieved to determine their stability. The aggregate separates were placed on the corresponding smaller sieves of the wet sieving apparatus (the sieves used were 4-mm and smaller for the larger aggregate fraction, 2-mm and smaller for the intermediate aggregate fraction and 0.5 mm and smaller for the smallest aggregate fraction).

4.3.3.1 Aggregate Stability of 6.4-12.7 mm Aggregates

The largest percentages of aggregates of the 6.4-12.7 mm size range were retained on the 4-mm sieve (Table 4.3) and highly significant differences were observed among cropping systems ($P \leq 0.01$). The CG cropping system had the greatest aggregate stability with 82.3 % of the aggregates retained on the 4-mm sieve after wet sieving. The CL cropping system had 53.5 % of the aggregates retained on the 4-mm sieve which was not significantly different from the Bf cropping system, which retained 41.2 %. The Bf, Fb and CB cropping systems were not significantly different from each other with 41.2, 38.1 and 35.0 % of the aggregates from the same fraction being retained with wet sieving on the 4-mm sieve.

Most of the aggregates broke down under wet sieving into smaller aggregates which were collected on the smaller sieves. The amount of the total aggregate fraction that went through the 0.125-mm sieve was the least for CG cropping system (1.4 %) and the greatest for the CB cropping system (11.1 %), but differences were not significant. The bulk of the aggregates from the Fb cropping system broke down into smaller aggregates when sieved. The greatest amounts were collected on the 1.0-0.5, 0.5-0.25 and 0.25-0.125 mm sieves with 11.1, 16.0 and 10.7 %, respectively. For the CG cropping system, the amounts collected on each of the smaller sieves was 4.1 % or less. The distribution of aggregates for the Bf and CB cropping systems was similar to that of the Fb cropping system. The CL cropping system had 46.5 % of its aggregates break down with wet sieving with each of smaller sieves collecting between 7.2 and 9.4 % of the total aggregates.

There was a significant difference in MWD among the cropping systems ($P \leq 0.01$). The MWD for the CG cropping system was the largest and was significantly different from all other cropping systems. The CL cropping system MWD was intermediate and also was significantly different from the other cropping systems except the Bf. There were no significant differences among the Fb, Bf and CB cropping systems.

Table 4.3 Aggregate stability of dry sieved aggregates (6.4-12.7 mm) using the wet sieving apparatus.

Aggregate size mm	Cropping System					Significant level
	CB[1]	Bf	Fb	CG	CL	
	(%)					
>4.0	35.0 c	41.2 bc	38.1 c	82.3 a	53.5 b[2]	**[3]
2.0 -4.0	10.0 a	10.2 a	8.0 a	4.1 b	7.2 ab	*
1.0 -2.0	7.6 a	8.8 a	8.3 a	3.4 b	7.4 a	*
0.5 -1.0	10.8 a	10.4 a	11.1 a	3.3 b	8.6 a	*
0.25 -0.5	14.3 a	12.7 ab	16.0 a	3.3 c	9.4 b	**
0.125-0.25	11.2 a	10.1 ab	10.7 a	2.2 c	7.8 a	**
<0.125	11.1	6.6	7.8	1.4	6.1	ns
	mm					
MWD	2.7 c	3.1 bc	2.8 c	5.1 a	3.7 b	**

[1] see table 4.1.

[2] same lowercase letters in a row indicates no significant differences between cropping systems.

[3] Significant levels: ** ≤0.01, * ≤ 0.05 and ns is not significant at ≤0.05.

Table 4.4 Aggregate stability of dry sieved aggregates using the wet sieving apparatus for the 2.4-6.4 mm aggregates.

Aggregate size mm	Cropping System					Significant level
	CB[1]	Bf	Fb	CG	CL	
	(%)					
2.0 -4.0	32.1 c	36.3 bc	32.5 c	63.4 a	44.3 b[2]	**[3]
1.0 -2.0	15.5	15.7	15.7	14.5	15.9	ns
0.5 -1.0	12.5 a	11.2 ab	12.0 ab	5.7 c	9.6 b	**
0.25 -0.5	16.4 a	13.3 ab	16.4 a	5.1 c	10.3 b	**
0.125-0.25	12.8 a	9.8 b	12.3 a	4.4 d	7.5 c	**
<0.125	10.8	13.8	11.2	6.9	12.5	ns
	mm					
MWD	2.8 b	3.0 b	2.8 b	4.4 a	3.4 b	**

[1] see table 4.1.

[2] Same lowercase letters in a row indicates no significant differences between cropping systems.

[3] significant levels: *≤0.01, * ≤ 0.05 and ns is not significant at ≤0.05.

4.3.3.2 Aggregate Stability of 2.4-6.4 mm Aggregates

The 2.4-6.4 mm aggregates from the CG cropping system were significantly more stable than those from other cropping systems (Table 4.4). This cropping system had 63.4 % of its aggregates retained on the 2-mm sieve. The aggregates from the CL cropping system were significantly more stable than those of the Fb and CB cropping systems with 44.3 % being retained on the largest sieve. The Bf cropping system had 36.3 % of its original aggregates retained on a 2-mm sieve which was not significantly different from the CL or the Fb and CB cropping systems.

Each of the cropping systems had approximately 15 % of its aggregates break down into the 1.0-2.0 mm size and there were no significant differences. Similar amounts of aggregates were collected on the sieves smaller than 1-mm for the Fb, Bf and CB cropping systems. The amounts retained on the sieves smaller than 1.0 mm were significantly less for the CG cropping system and intermediate for the CL cropping system. No significant differences were observed between the cropping systems for the less than 0.125 mm fraction.

The MWD of the 2.4-6.4 mm aggregate fraction was significantly different among the cropping systems ($P \leq 0.01$). The CG cropping system had the largest MWD (4.4 mm) which was significantly different from the other cropping systems. No differences were observed among the CL, Bf, Fb and CB cropping systems.

4.3.3.3 Aggregate Stability of 0.84-2.4 mm Aggregates

Statistical differences for the stability of the 0.84-2.4 mm aggregates were observed for all but the less than 0.125 mm fraction (Table 4.5). The CG cropping system had a significantly greater amount of its aggregates retained on the 0.5-mm sieve (65.4 %). The CL cropping system had the next greatest stability as it had 57.5 % of its aggregates retained on the 0.5-mm sieve but this cropping system was not significantly different from the Fb and Bf cropping systems. The least stable aggregates from the 0.84-2.4 mm fraction were observed for the CB cropping system which had 49.0 % of its aggregates retained on the 0.5-mm sieve.

The breakdown pattern of the 0.84-2.4 mm aggregates by the wet sieving technique was very similar for the Fb, Bf and CB cropping systems. These cropping systems had about 15 % of the 0.84-2.4 mm aggregates breakdown into 0.25-0.5 mm aggregates and a further 14 % breakdown into 0.125-0.25 mm aggregates. The CL cropping system had about 13 and 10 % of aggregates breakdown into the 0.25-0.5 and 0.125-0.25 mm size fractions, respectively, while the CG cropping system had only between 6 and 7 %. The amount of aggregate material retained on the 0.25-mm sieve (0.25-0.5 mm fraction) was significantly less for the CG cropping system compared to the other cropping systems. The 0.125-0.25 mm fraction aggregates retained from the CG and CL cropping systems were significantly less and were also significantly different from each other. The amounts of soil material passing through the 0.125-mm sieve was nearly the same for each cropping system at about 20 % with no significant differences among the cropping systems.

The MWD of the aggregates for the 0.84-2.4 mm aggregate fraction were significantly different among cropping systems ($P \leq 0.05$). The MWD for the CG cropping system was the greatest (4.4 mm) but was not signicantly different from that of the CL cropping system (4.1 mm). There were no significant differences in the MWD among the CL, Bf, Fb and CB cropping systems.

4.3.3.4 Comparison of Three Aggregate Fractions

Aggregate stability was different among the three dry aggregate fractions when subjected to wet sieving. The average stabilities of the aggregate fractions, determined from what was retained on the largest sieve, were very similar, 50.0, 41.7 and 54.9 % respectively, for the 6.4-12.7, 2.4-6.4 and 0.84-2.4 mm size fractions. The difference between the minimum and maximum stabilities (range) decreased considerably with decreasing aggregate size fractions. The range for the three fractions from largest to smallest was 47.3, 31.3 and 16.4 %, respectively. As the aggregate size decreased, the differences among the cropping systems became less.

4.3.4 Waterdrop Method

The number of drops required to disperse or disintegrate an aggregate of the 0.15-0.25 mm size ranged from 22.4 to 43.5 for the five cropping systems (Table 4.6). The CB cropping system had the least stable aggregates and the CG cropping system the most stable. The CG cropping system was significantly more stable than the CB, Bf and Fb cropping systems. The number of drops required to disintegrate an aggregate from the CG cropping system was nearly twice that of the CB cropping system while the CL cropping system aggregates required about 10 drops less than the CG cropping system. Cropping systems with decreased frequency of cultivation and a greater proportion of forage had greater aggregate stability.

4.3.5 Dispersion and Slaking Indices and Ratios

The dispersion index was not statistically different among cropping systems. The dispersion index ranked as follows:

Table 4.5 Aggregate stability of dry sieved aggregates using the wet sieving apparatus for the 0.84-2.4 mm aggregates.

Aggregate size mm	Cropping System					Signi-ficant level
	CB[1]	Bf	Fb	CG	CL	
			(%)			
>0.5	49.0 c	52.5 bc	50.2 bc	65.4 a	57.5 b[2]	**[3]
0.25 -0.5	16.5 a	14.0 a	15.6 a	6.9 b	13.3 a	**
0.125-0.25	14.4 a	13.3 a	13.7 a	5.5 c	9.7 b	**
<0.125	20.1	20.2	20.5	22.3	19.6	ns
			mm			
MWD	3.8 b	3.9 b	3.8 b	4.4 a	4.1 ab	*

[1] see table 4.1.

[2] same lowercase letters in a row indictes no significant differences between cropping systems.

[3] significant levels: ** ≤0.01, * ≤ 0.05 and ns is not significant at ≤0.05.

Table 4.6 Aggregate stabilty of aggregates from five different cropping systems by the McCalla waterdrop method (number of drops required to disperse aggregate).

	Cropping System				
	CB	Bf	Fb	CG	CL
Number of waterdrops	22.4 b	25.7 b	29.5 b	43.5 a	33.6 ab[2]

[1] see table 4.1.

[2] same lowercase letters in column indicates no significant differences (P≤0.05) between cropping systems.

Table 4.7 Carbohydrate amounts (mg g^{-1} of soil) for four different aggregate fractions of each cropping system.

Aggregate size mm	Cropping System					Signi-ficant level
	CB	Bf	Fb	CG	CL	
12.7 -6.4	12.9 b	13.1 b	12.8 b	20.2 a	15.3 b[1]	**[2]
6.4 -2.4	10.8 b	11.4 b	10.5 b	13.9 a	11.3 b	*
2.4 -0.84	10.7 bc	10.8 bc	9.2 c	13.9 a	11.6 b	**
0.84-0.42	11.2	10.4	10.3	12.8	10.8	ns
Mean	11.4 b	11.4 b	10.6 c	15.2 a	12.2 b	**

[1] see Table 4.1.

[2] same lowercase letters in a row indictes no significant differences between cropping systems.

[3] significant levels: ** ≤0.01, * ≤ 0.05 and ns is not significant at ≤0.05.

CB < Fb < Bf < CL < CG. The range of the index was very small, 1.5 to 2.8, making it very difficult to distinquish differences among the cropping systems (Figure 4.1). The same ranking was observed for the slaking index and the slaking/dispersion ratio (Figure 4.2). The slaking index for the CG cropping system (6.0) was significantly higher ($P \leq 0.05$) than the other cropping systems. The slaking indices for the other four cropping systems ranged from 2.3 to 3.7. The slaking/dispersion ratios of the different cropping systems were not significantly different.

4.3.6 Carbohydrates

Significant differences were observed in the amount of total carbohydrates for the different cropping systems (Table 4.7). The carbohydrate contents of the aggregate fractions for the CG cropping system were always greater than those of the other cropping systems. In the 6.4-12.7 mm aggregate fraction of the CG cropping system, the amount of carbohydrate was 20.2 mg g^{-1} of soil, which was significantly different ($P \leq 0.01$) from the other cropping systems (15.3 mg g^{-1} or less). A similar trend was observed for the 2.4-6.4 and 0.84-2.4 mm aggregate size fractions. The CG cropping system had 13.9 mg of carbohydrate g^{-1} of soil for each of these fractions. The 0.42-0.84 mm aggregate fraction did not show a significant difference among cropping systems even though the CG cropping system tended to have a higher carbohydrate content. The CG cropping system had a significantly greater mean carbohydrate content, over all four aggregate fractions, than the other four cropping systems ($P \leq 0.01$). The Fb cropping system had significantly lower mean levels of carbohydrate compared to the Bf, CB and CL cropping systems which were not significantly different from

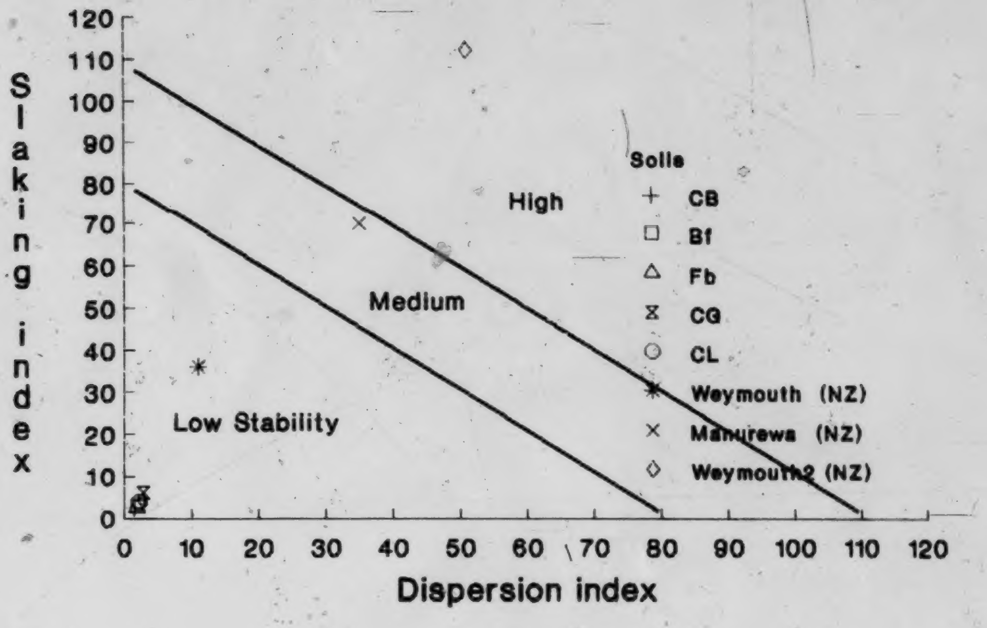

Figure 4.1 Dispersion and slaking indices for five cropping systems in comparison to three New Zealand soils (McQueen 1982) with a wide range of aggregate stabilities.

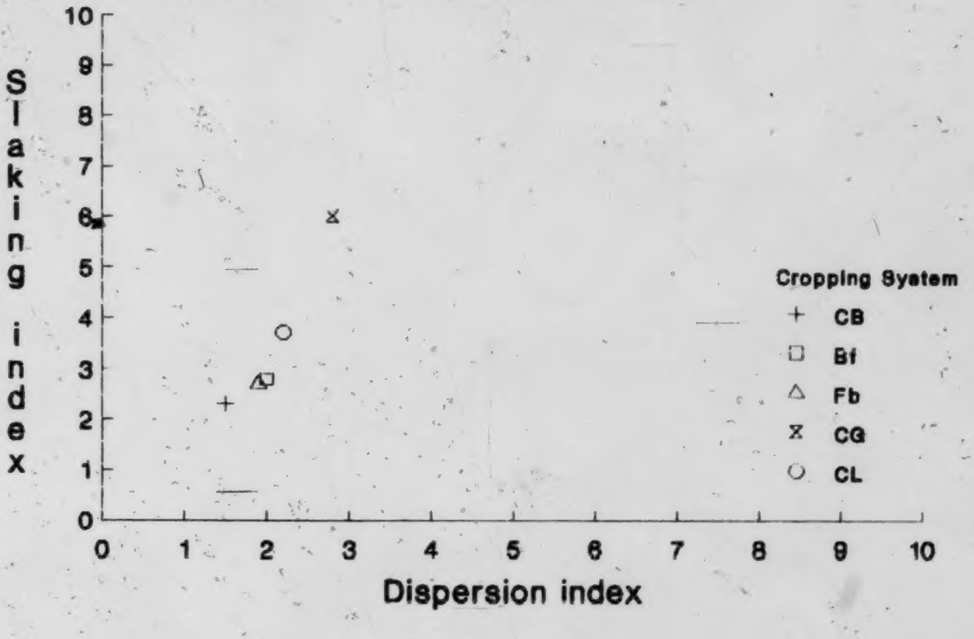

Figure 4.2 Dispersion and slaking indices plotted on an expanded scale for easier comparison of cropping system aggregate stabilities.

each other ($P<0.01$).

The average amount of carbohydrate in the aggregates across cropping systems was the greatest for the largest aggregate fraction (12.7-6.4 mm) with 14.9 mg g^{-1} of soil, and decreased with decreasing aggregate size. The average carbohydrate mass per gram of soil decreased slightly from 12.0, 11.2 to 11.1 mg for the 6.4-2.4, 2.4-0.84 and 0.84-0.42 mm aggregate size fractions, respectively.

4.4 DISCUSSION

4.4.1 Aggregate Distribution

The CL cropping system had a significantly different aggregate distribution from the other cropping systems. By the rotary dry sieving technique, this cropping system had fewer aggregates in the larger size fractions (6.4-12.7 and 2.4-6.4 mm) and a larger proportion in the smaller fractions (0.42-0.84 and <0.42 mm) than the other cropping systems. This corresponded to how the CL cropping system soil handled upon drying in the laboratory as it broke down into smaller aggregates readily when handled and flowed more readily through the sieve (2 mm) than the other cropping system soils. The preparation of the seed bed would be easier with the CL cropping system as it has better tilth. The CB, Bf, Fb and CG cropping systems had very similar dry aggregate distributions.

The aggregate distribution by wet sieving versus dry sieving differed. The CG cropping system had the greatest amount of aggregates in the >4.0 and 2.0-4.0 mm aggregate fractions with wet sieving. The aggregate samples of the other cropping systems disaggregated more readily into smaller aggregates or peds by wet sieving and there were no significant differences among them. The aggregate distribution for the CL cropping system was the most similar between the dry and wet sieving methods.

Method of determining aggregate distribution has a strong influence on the results (Kemper and Rosenau 1986). The aggregates from the CG and CL cropping systems were influenced the least by the two methods while many of the larger aggregates from the CB, Bf and Fb cropping system disaggregated when wet sieved. Chepil (1951,1958) showed that the mechanical stability of dry aggregates is an index of vulnerability of the soil to wind erosion. Thus if the soils were tilled and kept bare, the CL cropping system would be the most susceptible to wind erosion while the other cropping systems have similar susceptibility. The wet sieving technique, on the other hand, indicated that the soils under the CG and the CL cropping systems are the most resistant to aggregate breakdown from the impact of precipitation and water erosion. The other cropping systems had very similar aggregate distributions that were not significantly different from each other.

The MWD gives a single index for aggregate distribution (van Bavel 1949, Youker and McGuinness 1956). The MWD determined for the dry and wet aggregate distributions indicated that these two methods measure different parameters. Kemper and Rosenau (1986) indicated that the different forces involved in aggregate size and stability include i)impact and shearing forces delivered during sampling and sample preparation, ii)abrasive and impact forces during sieving and/or iii)forces involved with the entry of water into the aggregate. These forces, according to Kemper and Rosenau (1986), are related to cultivation, erosion (wind and water), and wetting of soils, respectively. According to Chepil (1962) dry sieving is a sensitive measure of soil structure differences resulting from amendment, fertilization and cropping of soils. The results from the dry sieving aggregate distribution indicated that the CL cropping system would be more prone to wind erosion because it had a significantly larger number of small aggregates (<0.84 mm). There were no differences among the other cropping systems. The continuous growing of forage for the CL cropping system did not result in a larger MWD. The CG cropping system would be the most resistant to water erosion as indicated by the wet sieving technique. The CB, Bf, Fb and CL cropping systems were not different from each other in susceptibility to water erosion when the whole soil was used.

4.4.2 Aggregate Stability Assessment

The stability of dry sieved aggregates as determined by wet sieving, the waterdrop method and the slaking/dispersion index provided similar trends. The wet sieving of selected aggregate fractions indicated that the aggregates from the CG cropping system were the most stable. The next most stable aggregates were from the CL cropping system. The CB cropping system had the least stable aggregates, but the stability was not significantly different from that of the Bf or Fb cropping systems.

The MWD for the aggregate stability determinations by wet sieving resulted in the same order of stabilities for each of the different aggregate size fractions from the different cropping systems: CG > CL > Bf > Fb = CB. The aggregate stabilities are a reflection of the cropping history and frequency of cultivation. The results of this study were silmilar to those obtained by Low (1972) which showed that increased cultivation resulted in the deterioration of soil aggregation. This was reflected by fewer large aggregates and lower aggregate stability of cropping systems such as CB, Bf, and Fb with increasing frequency of cultivation.

The CG cropping system had the most stable aggregates as indicated by the McCalla waterdrop method. The least stable aggregates were found in the the CB cropping system. The slaking/dispersion index also indicated that the CG cropping system aggregates were the most stable but that there were no significant differences among the other cropping systems. The slaking/dispersion index was not considered suitable for the Luvisolic soils because the treatment by this method was too severe for these soils and meaningful separations of treatments could not be obtained when compared to the aggregate stablities of New Zealand soils (McQueen 1982, personal communication).

Organic matter has been positively correlated with aggregation (Harris et al. 1966, Lynch and Bragg 1985, Burns and Davies 1986). It is not only the addition of organic matter but the manner and rate of decomposition that leads to aggregate formation. The greatest amount and stability of aggregates occurred under continuous perennial forages such as grasses and legumes from the CG and CL cropping systems. The lower stabilty of the CL compared to CG cropping system was likely due to more fallow and cultivation that occurred in this cropping system (Baldock and Kay 1987) and the type of organic matter added (low C to N ratio) which would make it more susceptible to rapid decomposition. The CL cropping system would have been subjected to disaggregation when it was fallowed from 1975 to 1977 inclusive, and during re-establishment three other times during the 17 year period (Chapter 2). The CG cropping system, on the other hand, was only re-seeded in the spring following fall plowing on two occasions over the same time period. The lower stabilty of the CB cropping system is a reflection of the frequent (annual) cultivation, lower levels of residues and roots, and the two fallow periods. The higher stability of the Bf cropping system compared to the Fb cropping system is a reflection of the time of sampling as the Bf cropping system had recently been in three years of forage production.

4.4.3 Carbohydrate Contents

Aggregate stability has been positively correlated with carbohydrate content (Harris et al. 1966, Burns and Davies 1986). The aggregates from the CG cropping system had the greatest carbohydrate contents. In this study the carbohydrate contents decreased with decreasing aggregate size, opposite to the observation of Baldock et al. (1987). The most stable aggregates had the highest carbohydrate contents. The lowest carbohydrate content of the Fb cropping system was not reflected completely in the aggregate stability as its aggregates were slightly more stable than those from the CB cropping system.

4.5 CONCLUSIONS

The distribution of aggregates is strongly influenced by the measurement technique used. The rotary dry sieve resulted in similar aggregate distributions for the CG, Bf, Fb and CB cropping systems. The CL cropping system had fewer large aggregates and more small aggregates by the dry technique. Wet sieving, by contrast indicated that the CG cropping system had greater amounts of large aggregates while the CL, Bf, Fb and CB cropping systems were very similar to each other.

The decreasing stability of the aggregates measured with wet sieving from the different cropping systems was in the order: CG >CL >Bf >Fb ≥CB. The stability of the Bf cropping system was greater than that of the Fb cropping system because it had recently been in forage. The aggregate stability results were consistent among the methods used, wet sieving, the waterdrop method and the slaking/dispersion index. The MWD of aggregates from the wet sieving of the different size fractions resulted in the same ranking of aggregate stabilities. Aggregate stability among the different cropping systems was not affected by the aggregate sizes using the wet sieving technique. The aggregate stability of the 0.84-2.4 mm aggregates was greater when compared to the 6.4-12.7 mm aggregates for all except the CG cropping system. The aggregate stability of the CG cropping system decreased from 82.3 to 65.4 % for these fractions. The intermediate aggregate size fraction (2.4-6.4 mm) had lower stabilities in all cases.

The carbohydrate content of the aggregates from the CG cropping system was the highest for all the aggregate size fractions and the lowest for the Fb cropping system. The amounts of carbohydrates decreased with decreasing aggregate size.

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CHAPTER 5

Net Nitrogen Mineralization from a Luvisolic Soil Under Diverse Cropping Systems in the Peace River Region of Alberta

5.1 INTRODUCTION

Nitrogen (N) is a growth limiting nutrient in most Luvisolic soils of Alberta (Wyatt and Ward 1929, McGill 1982, Robertson and McGill 1983). Commercial arable agriculture requires that annual cereal and oilseeds be supplied with N in organic form (eg. manure, plowdown) and/or as inorganic N fertilizers. Management of such systems requires the ability to predict the quantity of N mineralized annually.

Biological and chemical methods have been developed as indices of N availability. Chemical methods are empirical and make no allowance for microbial mediated N mineralization-immobilization reactions. The biological methods, involving estimation of the amount of mineral-N found after incubation, have been extensively utilized and are considered satisfactory for the assessment of the potential ability of soils to provide N for crop growth (Bremner 1965). Stanford and his co-workers (Stanford and Smith 1972, Stanford et al. 1973, Stanford and Epstein 1974) advanced the concept that potentially mineralizable N (N_o) mineralizes according to first order kinetics with a rate constant (k). The values of N_o and k can be obtained by mathematical anaysis of mineral N accumulation curves obtained in long-term laboratory incubation (Stanford and Smith 1972). The value obtained for N_o is affected by moisture (Myers et al. 1982), aeration, temperature (Cassman and Munns 1980), nature and quantity of organic matter (Stanford 1968, Janzen and Kucey 1988, Smith and Sharpley 1990), nature and quantity of the previous crop residue (Janzen and Kucey 1988, Campbell et al. 1990a) and years under cultivation (Campbell and Souster 1982).

The influence of agricultural practices on soil organic matter content and quality have been assessed to a limited degree using various chemical and biological parameters (Campbell et al. 1990b). Generally organic matter, organic carbon, or organic N are used as the main indicators of quantity (Campbell 1978, Biederbeck et al. 1984, Janzen 1987a, 1987b, Campbell et al. 1990a) because these parameters are easily determined. Others have characterized organic matter by hydrolysis with strong acid to identify and quantify amino sugars and amino acids (Sowden 1968, Khan 1971, Stevenson 1982, Campbell et al. 1990b). The effectiveness of these parameters in demonstrating qualitative changes in the soil organic matter is limited (Sowden 1968, Stevenson 1982, Campbell 1990b). Recently less drastic methods have been utilized to characterize soil organic matter and determine how it is affected by management practices such as cropping systems, fertilizers and tillage practices. These methods include microbial biomass (Biederbeck et al. 1984, McGill et al. 1986, Bonde et al. 1988), N_0 and mineralizable C (Stanford and Smith 1972, El-Harris et al. 1983, Biederbeck et al. 1984, Janzen 1987b, Bonde et al. 1988), the time required to mineralize fixed amounts of N (El Gharous 1990) and the instantaneous rate (N_0*k) of mineralization (Campbell et al. 1990a).

In this study surface soils from the Beaverlodge Long-term Cropping System Field Experiment were evaluated to determine: i)the accumulated release of NH_4-N, NO_3-N and total mineral-N during incubation for each of the cropping systems, ii)the values of N_0 and k using the exponential model for the cropping systems and iii)the instantaneous mineralization rates and time required to mineralize a fixed amount of N from each cropping system.

5.2 MATERIALS AND METHODS

5.2.1. Soils and Sampling

The cropping systems were first established in 1968 and consisted of:

1. continuous barley (CB),
2a. barley (Bf): 3 years barley followed by 3 years forage,
2b. forage (Fb): 3 years forage followed by 3 years barley,
3. continuous grass (CG) and
4. continuous legume (CL).

The Bf and Fb cropping systems were generally alternated every three years. The forage component of the Fb and Bf cropping system consisted of bromegrass (Bromus inermis, cv 'Carlton') and red clover (Trifolium pratense, cv 'Norlac'), the CG cropping system of bromegrass and the CL cropping system of red clover. The barley (Hordeum vulgare, cv 'Galt') was harvested as grain while the forage crops were harvested as hay. A more detailed description of the Beaverlodge Long-term Cropping System Field Experiment and its management was described in Chapter 2.

The year prior to sampling (1983) was wetter than normal resulting in poor yields of barley for the CB and Bf cropping systems (960 and 510 kg ha^{-1}, respectively) (Appendix 8.3). The CB cropping system and the new Bf cropping system which came out of forage (Fb) production system were fallowed during the 1984 growing season mainly because May and June had above normal precipitation and to control weeds. The Fb cropping system which had been in barley (Bf) production was reseeded to a mixture of bromegrass and red clover but was not harvested during the establishment year. The CG cropping system had been in continuous forage production since it was reestablished in 1978. The CL cropping system had been reestablished 1983, and 1984 was the first harvest from this new seeding. Nitrogen fertilizer was applied in the spring of 1984 to all cropping systems at rates of 47.6 kg ha^{-1} for the CB and Bf cropping systems and at 95.2 kg ha^{-1} for the Fb, CG and CL cropping systems. The CB and Bf cropping systems received fertilizer because the fallow was not planned.

Soil samples were taken from the Beaverlodge Long-term Cropping System Field Experiment in the late summer of 1984 from the 0-15 cm depths from each of the four replicates of the five cropping systems. Representative surface samples were obtained by sampling with a narrow square nosed shovel at 10 random locations throughout each plot. The samples were air-dried and passed through a 2 mm stainless steel sieve and the larger organic debris was removed. Bulk samples from each cropping system were prepared by mixing equal volumes of soil from each replicate.

5.2.2 Nitrogen Mineralization Procedure.

For each cropping system, three soil subsamples (25 g) and acid washed sand, 0.5-1.0 mm, (25 g) were mixed in 100 ml beakers and transferred to 5.5 cm plastic Buchner funnels. A fiber-glass filter disk was placed below and on top of the soil. The top filter disk was to protect the soil sample from disaggregation and slaking during leaching (McKay and Carefoot 1981, Bonde and Rosswall 1987). The leaching solution consisted of 60 ml of 0.01 M $CaCl_2$ followed by 20 ml of minus N nutrient solution (Stanford and Smith 1972). The samples were leached at 0, 2, 4, 8, 12, 16 and 20 weeks. The leaching solution was added to the Buchner filter in 20 ml increments, allowed to equilibrate for 10 minutes before being extracted from the sample by vacuum (about 60 kPa). The leachate was collected in 250 ml filter flasks using a vacuum pump. After the final leaching the samples were subjected to suction for a further 5 minutes to remove excess leachate. The leachates were transferred to 100 ml volumetric flasks and brought to volume, part of this solution was transferred to 60 ml plastic bottles and refrigerated.

Between leachings the moist soil samples were enclosed in plastic bags to minimize drying. The samples were incubated in the dark at 30±1°C and aerated twice a week. Distilled water (2 ml) was added to the samples weekly when the time between leachings was greater than two weeks.

5.2.3 Chemical Analyses

The pH of the bulk soil samples was determined in H_2O and 0.01 M $CaCl_2$ (Peech 1965). Total carbon (C) was determined by dry combustion using a Leco Carbon Determinator model CR-1. Total N was determined by the macro-Kjeldahl method (Bremmer 1965). The C to N ratio was calculated from these results. Available NO_3-N and NH_4-N were extracted from the soil samples with 0.01 M $CaCl_2$ and 2 N KCl, both seperate extractants used 5 g of sample and 50 ml of extractant. Samples were shaken for 1 hr on a reciprocal shaker at 30 cycles min^{-1} and gravity filtered. The NO_3-N and NH_4-N in the extractants and leachates were determined on a Technicon Analyzer II. Nitrate-N was determined with the Technicon Industrial Method 487-77A (Technicon 1977) and NH_4-N by the Technicon Industrial Method 98-70W (Technicon 1978). Total mineral-N was calculated by the summing of NH_4-N and NO_3-N.

5.2.4 Mineralization Model

Mineralization has commonly been described by first order or exponential model (Juma et al. 1984, Ellert and Bettany 1988) having the equation:

$$N_m = N_o(1-\exp^{-k*t}) \qquad \text{equation 1}$$

where N_m is the cumulative net N mineralized up to time t (weeks), k is the invariant rate constant ($weeks^{-1}$) and N_o is defined as the potentially mineralizable N pool at t=0.

The first derivative of equation 1 is:

$$dN_m/dt = (N_o*k)e^{-kt} = (N_o*k)e^0 = N_o*k \qquad \text{equation 2}$$

The first derivative shows that the rate of mineralization decreases with time and that it is a function of N_o and k. Cambell et al. (1990a) have calculated the instantaneous mineralization rate at time = 0 (N_o*k).

5.2.5 Statistical Analyses

The chemical and modelling data were analyzed using the SAS statistical package (SAS Inc. 1982). Analyses of variance (ANOVA) for chemical data, regression (REG) for comparisons between $CaCl_2$ (0.01 M) and KCl (2 N) extractions and non-linear regression (NLIN) to fit mineralization data to the exponential model, were utilized. The experimental design for ANOVA was a randomized block. A protected Duncan's Multiple Range test was used to determine significant differences on main effect means from ANOVA. Model discrimination was used to compare models (Robinson 1985, Beck and Arnold 1977).

5.3 RESULTS AND DISCUSSION

5.3.1 Cropping System Soil Characteristics

Selected chemical characteristics of the cropping system bulk soils after 17 years of cropping included pH in H_2O and $CaCl_2$, total C, total N and the calculated C to N ratio (Table 5.1). The pH values of the cropping system soils were not different. The mean pH values of the cropping systems were 5.8 in H_2O and 5.1 in $CaCl_2$ with the pH in $CaCl_2$ between 0.6 and 1.0 pH units lower than in H_2O. Differences among cropping systems in pH because of nitrogenous fertilizers were not observed as had been by McCoy and Webster (1977) and Nyborg and Mahli (1981). The CB, Bf, Fb, CG and CL cropping systems on average received very different N rates of 49, 44, 46, 60 and 20 kg ha^{-1} per annually, respectively (Chapter 2, Table 2.2).

Cropping systems had different amounts of total C. The CG cropping system had the highest C (4.37%) which was different from the CB (3.48%), Bf (3.36%) and Fb (3.47%) cropping systems but not from the CL (4.02%) cropping system. Total N was not different among the cropping systems. The C to N ratios for the cropping systems ranged from 11.6 to 13.7 and were not statistically different.

The CB, Bf and Fb cropping systems, which required more frequent cultivation and fallowing compared to the CL and CG cropping systems, had lower amounts of organic matter. Increased cultivation has been reported to decrease the amount of organic matter in soils (Campbell et al. 1976, McGill and Hoyt 1977, Robertson 1979, Reinl 1984). The growing of annuals (barley) resulted in the soil not having an actively growing crop or crop cover for a large part of the year because of fall tillage and spring seeding resulting in less root mass and less photosynthate being directed to the roots.

Amounts of mineral NO_3-N extracted by $CaCl_2$ (0.01 M) or KCl (2 N) method were highly correlated ($r=0.999$, $P\leq 0.001$) (Table 5.2). The amount of NO_3-N extracted was the highest for the cropping systems in

Table 5.1 Chemical characterization of soil from each cropping system as to pH, C, N and C to N.

Cropping System[1]	pH		C	N	C/N ratio
	H_2O	$CaCl_2$	%		
CB	5.8	5.1	3.48 b[2]	0.30	11.6
Bf	5.8	5.0	3.36 b	0.26	12.9
Fb	6.1	5.1	3.47 b	0.28	12.4
CG	5.7	5.1	4.37a	0.32	13.7
CL	5.8	5.1	4.02ab	0.32	12.6
Significance Level	NS[3]	NS	**	NS	NS

[1] CB-continuous barley, Bf-barley/forage, Fb-forage/barley, CG-continuous grass and CL-continuous legume.

[2] means in columns followed by different letters are significantly different from each other.

[3] NS -not significant, **-significant at $P \leq 0.01$.

Table 5.2 Initial available NH_4-N and NO_3-N extracted by $CaCl_2$ and KCl for each cropping system.

Cropping System[1]	$CaCl_2$ (0.01M)		KCl_2 (2N)	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N
	mg kg^{-1} of soil			
CB	2.23	77.60a[2]	22.40	78.00a
Bf	4.05	68.00a	22.30	67.90a
Fb	3.69	7.43 b	27.20	7.44 b
CG	2.34	12.10 b	25.90	12.50 b
CL	6.83	10.40 b	32.80	10.10 b
Significance Level	NS[3]	**	NS	**

[1] see Table 5.1.

[2] means in columns followed by different letters are significantly different from each other.

[3] NS -not significant, **-significant at $P \leq 0.01$.

barley (CB and Bf) which had 78 and 68 mg kg^{-1} of NO_3-N, respectively. These two cropping sytems had significantly more available NO_3-N compared to the Fb, CG and CL cropping systems which had between 7.4 and 12.5 mg kg^{-1} ($P \leq 0.004$) because during the 1984 growing season these cropping systems were fallowed resulting in the accumulation of mineralized NO_3-N.

A significant correlation was also observed between the two methods for the amounts of NH_4-N extracted ($r=0.692$, $P \leq 0.001$). The KCl method, on average, extracted about 7 times as much NH_4-N as did the $CaCl_2$ method, however. No significant differences among cropping systems were observed in the amount of NH_4-N extracted by either method. The differences in the amount of NH_4-N extracted by the two methods reflect soil properties and not cropping systems as NH_4-N is readily adsorbed to the soil (Cameron and Haynes 1986) while the NO_3-N has little tendency to be adsorbed on the soil colloids.

5.3.2 Nitrogen Accumulation

5.3.2.1 NH_4-N Accumulation

Cumulative NH_4-N during the incubation period followed the same trend for all cropping systems. The initial accumulation was rapid but after 4 weeks became almost negligible (Fig. 5.1). The accumulation of NH_4-N at the start of a growing season would be beneficial as NH_4 can be adsorbed to the soil complex and not be leached readily from the soil system during the period when plants are not growing actively..

The total accumulation of NH_4-N for the cropping systems up to 20 weeks was different (Table 5.3). The CL and CG cropping system accumulated the greatest amounts of NH_4-N (21.9 and 24.5 mg kg^{-1}) and were different from the other cropping systems. The Fb cropping system accumulated an intermediate amount of NH_4-N (12.5 mg kg^{-1}) which was different from all the other cropping systems. The CB and Bf cropping systems accumulated the least NH_4-N (7.0 and 8.9 mg kg^{-1}) probably because these cropping systems had been fallowed for the 1984 growing season and easily mineralizable organic N had been released during that period.

5.3.2.2 NO_3-N Accumulation

Cumulative NO_3-N during the 20 week incubation period exhibited the same general trend for the CB, Bf, Fb and CG cropping systems with decreasing rates of mineralization over time (Fig. 5.1). The rapid primary accumulation of NO_3-N for the CL cropping system continued for the full time of the incubation (20 weeks) resulting in a linear relationship ($r=0.991$, $P \leq 0.001$). Visual inspection of NO_3-N accumulation curve for the Bf cropping system indicated that it plateaued at about 4 weeks while the CB, Fb and CG cropping systems accumulation started levelling off at about 12 weeks.

Differences in accumulated NO_3-N after 20 weeks were observed among the cropping systems (Table 5.3). The CL cropping system accumulated the greatest amount of NO_3-N (184.7 mg kg^{-1}). The greater accumulation of NO_3-N from the CL cropping system is expected because the organic matter from the legume crop would have a narrower C to N ratio resulting in less immobilization of N with decomposition. The least NO_3-N was accumulated by the Bf cropping system (23.5 mg kg^{-1}) while intermediate amounts of 80.3, 85.2 and 109.2 mg kg^{-1} accumulated from the CG, CB and Fb cropping system soils, respectively. The lower amounts of NO_3-N accumulated from the Bf cropping system could not be explained readily as it had a similar organic matter and

Table 5.3 The amounts of NH_4-N, NO_3-N and total mineral-N accumulated after 20 weeks of mineralization for each of the cropping systems.

Cropping System[1]	Accumulated at 20 weeks NH_4-N	 NO_3-N	 total mineral-N	NH_4-N as % of total mineral-N
CB	7.0 c[2]	85.2 b	92.2 b	7.6
Bf	8.9 c	23.5 c	32.4 c	27.5
Fb	12.5 b	109.2 b	121.6 b	10.3
CG	24.5a	80.3 b	104.8 b	23.4
CL	21.9a	184.7a	206.6a	10.6
significance level	**[3]	**	**	ND

[1] see Table 5.1.

[2] means in columns followed by different letters are significantly different from each other.

[3] significant at $P \leq 0.01$, ND -not determined.

Table 5.4 Nitrogen mineralization potentials (N_o), rate constants (k) and the active N fraction estimated from the exponential model.

Parameter	Cropping System[1] CB	 Bf	 Fb	 CG	 CL
			mg kg^{-1} N		
N_o	85.3	29.2	121.8	105.9	364.2
			wk^{-1}		
k	0.233	0.255	0.180	0.229	0.043
			%		
N_o/Total N	2.84	1.12	4.35	3.31	11.38

[1] see Table 5.1.

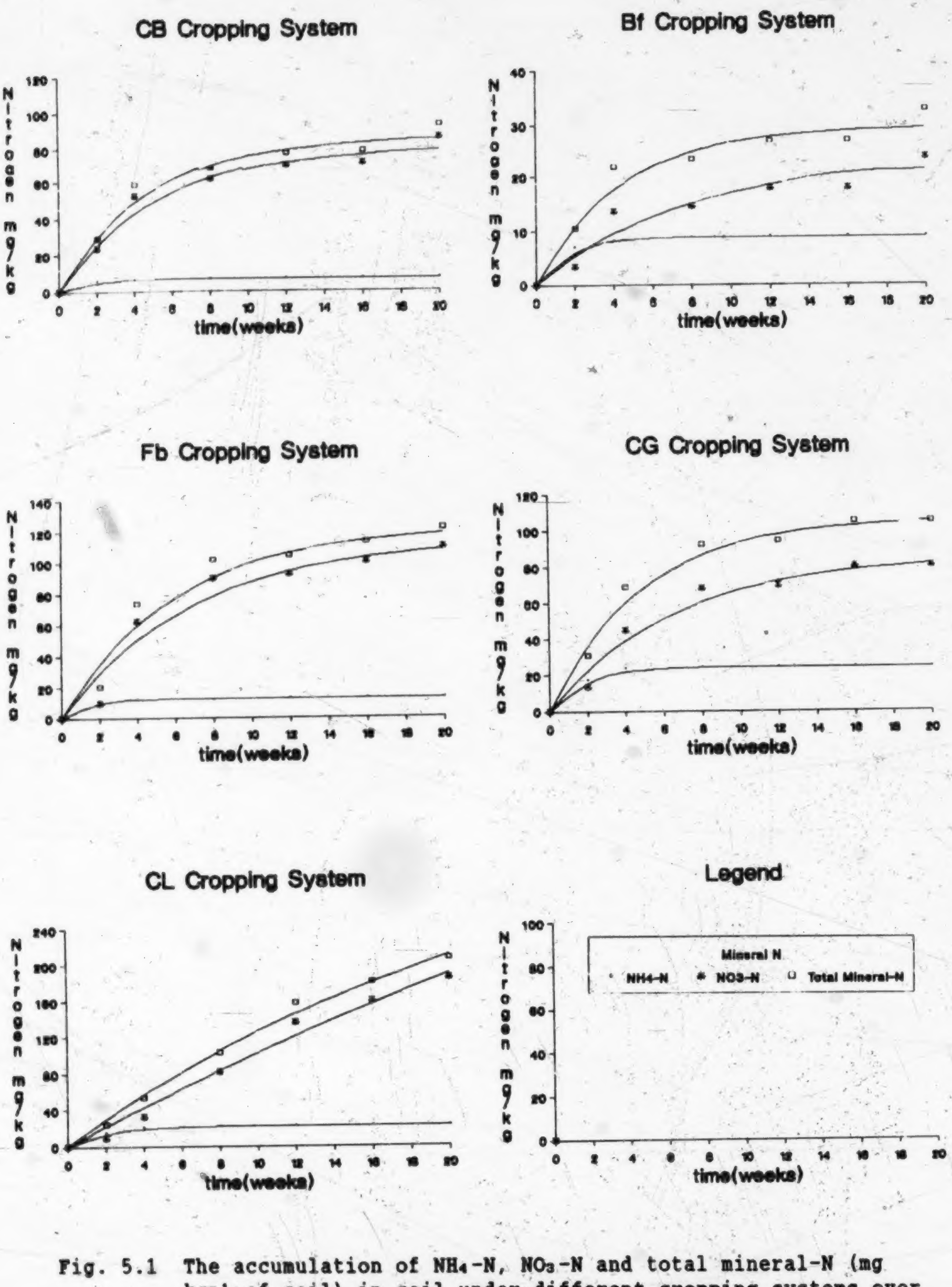

Fig. 5.1 The accumulation of NH_4-N, NO_3-N and total mineral-N (mg kg^{-1} of soil) in soil under different cropping systems over a 20 week period (note Y-axis are not scaled equally). Curves fitted to actual data using the exponential model.

total N content as that of the CB and Fb cropping systems. The Bf cropping system had recently come out of forage production and the CB and Bf cropping systems were fallowed for the growing season prior to sampling (1984) because of excess precipitation during seeding time. A considerable amount of N had mineralized and accumulated during the growing season for the CB and Bf cropping systems as was observed from the amounts of mineralizable N that was extracted with KCl (2N) prior to incubation (100.4 and 90.2 mg kg^{-1} of N, respectively. Table 5.2). It appears that there was much less readily available mineralizable N for the Bf cropping system.

5.3.2.3 Total Mineral-N Accumulation

The accumulation of total mineral-N was very similar to NO_3-N accumulation over the 20 week period because the accumulation of NH_4-N was basically complete by week 4 (Fig. 5.1). The NH_4-N accumulation initially was a substantial portion of the total mineral-N but became smaller over time. At 20 weeks the NH_4-N component made up about 25% of the total mineral-N for the CG and Bf cropping system while for the other cropping systems it had decreased to about 10%.

The total mineral-N accumulated at week 20 was different for the different cropping sytems. These differences followed the same trends that were observed for NO_3-N accumulation and the trends were minimally affected by the inclusion of the NH_4-N component.

The net total N accumulation decreased over time for the CB, Bf, Fb and CG cropping systems. The net total N accumulation data of the CL cropping system could be readily fitted to a linear model ($r=0.989$, $P\leq0.001$) and did not decreased over time as quickly as those of the other cropping systems.

5.3.3 Total Mineral-N Mineralization by the Exponential Model

5.3.3.1 Estimation of Cropping System N_o

The N_o was estimated for each of the cropping systems by the exponential model (Table 5.4). The Bf cropping system had the lowest N_o (29.2 mg kg^{-1} of N) while the CL cropping system had the highest (364.2 mg N kg^{-1}). The CB, CG and Fb cropping systems had intermediate N_o values of 85.3, 105.9 and 121.8 mg kg^{-1} of N, respectively. The estimated N_o for each cropping system was similar to results obtained from 20 weeks of mineralization except for the CL cropping system. The CL cropping system soil was still as actively mineralizing N at 20 weeks as at earlier stages while for the other cropping systems the rate of mineralization decreased markedly with time. The estimates of No are low compared to those reported in the literature (El Gharous 1990) because the plots were not cropped in 1984. Thus, the initial flush level of mineral N (Table 5.) must have originated from the N_o pool. The estimated N_o from incubation data is an underestimate.

5.3.3.2 Estimation of Rate Constant (k)

The k estimated from the exponential model ranged from 0.043 to 0.255 wk^{-1} (Table 5.4). The lowest and highest values were for the CL and Bf cropping systems, respectively. The Fb, CG and CB cropping systems had k values of 0.180, 0.229 and 0.255 wk^{-1}, respectively. These rate constants, except for the CL cropping system, were similar to those (0.060-0.168 wk^{-1}) reported by El Gharous (1990).

Because the CL cropping system mineralization rate was almost linear a discrimination procedure was used to determine which model, linear or exponential, best described the data (Robinson 1985, Beck and Arnold

1977). The sum of squares for the deviations for the exponential model was less than that from the linear model and the calculated F statistic, 10.13, was equal at $P<0.05$ ($F_{tabled} = 10.13$, df= 1,3) indicating that the exponential model was valid to describe the data.

5.3.3.3 The Active N Fraction

The active N fraction (N_o/total soil N) was calculated for each cropping system (Table 5.4) The active/total-N fractions were 1.12, 2.84, 3.31 and 4.35 % for the Bf, CB, CG and Fb cropping systems, respectively. The CL cropping system had an active/total mineral-N fraction that was much larger (11.38 %) than the other cropping systems. The active/total mineral-N fractions of the Bf, CB, CG and Fb cropping systems were considerably smaller than those reported by other researchers (Campbell and Souster 1982, El Gharous 1990) and only the CL cropping system was of the same magnitude. A smaller total amount of organic N is required by the CL cropping system to supply the same amount of mineralizable N compared to the other cropping systems.

5.3.4 Mineralization Rates

5.3.4.1 Mineralization Rate Curves from Exponential Model

The calculated mineralization rates of the cropping system soils all decreased with time (Fig. 5.2). Mineralization of N from the Bf cropping system soils was the lowest for the duration of the incubation, starting at about 7.5 mg $kg^{-1}wk^{-1}$ of N and finishing at week 20 at a rate of 0.05 mg $kg^{-1}wk^{-1}$ of N. The CB, Fb and CG cropping system soils had the highest initial N mineralization rates at about 20-24 mg $kg^{-1}wk^{-1}$ of N but decreased rapidly to 0.19, 0.60 and 0.25 mg of N $kg^{-1}wk^{-1}$ respectively, by week 20. The N mineralization rates of the CB, Fb, CG and CL cropping system soil were all similar at week 2

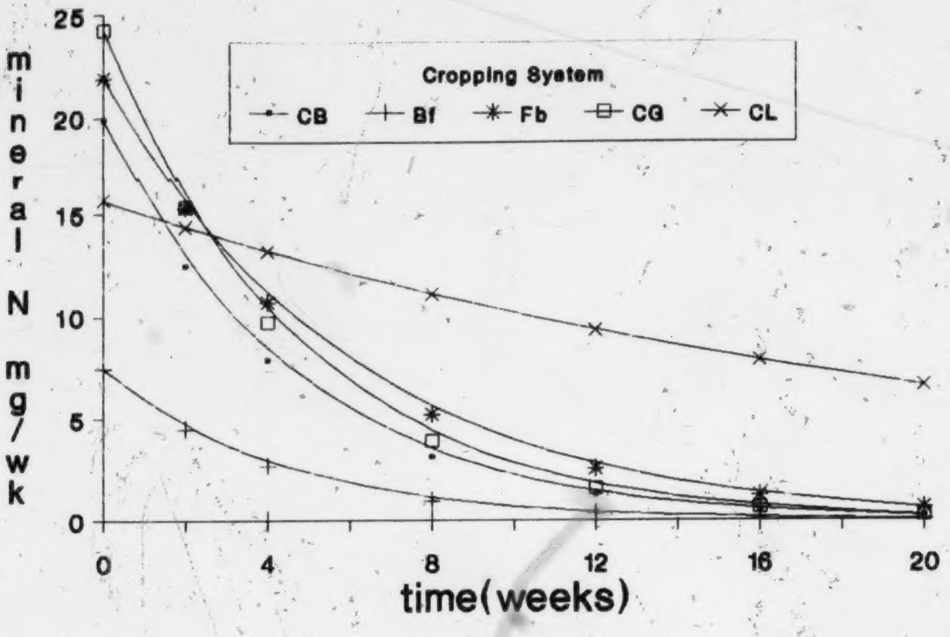

Fig. 5.2 Mineralization rates for the 5 cropping system soils over 20 weeks calculated using the exponential model.

Table 5.5 Instantaneous mineralization rates and the time required to mineralize fixed amounts of N determined by the exponential model.

Cropping System[1]	No*k	— Time in weeks required to mineralize — 10	25	50	100
	$\text{mg kg}^{-1}\text{wk}^{-1}$ N	mg kg^{-1} N			
CB	19.85(3)[2]	0.54(3)	1.49(3)	3.79(4)	ND(4)[3]
Bf	7.45(5)	1.65(5)	7.61(5)	ND(5)	ND(5)
Fb	21.92(2)	0.48(2)	1.28(2)	2.94(2)	9.56(2)
CG	24.22(1)	0.43(1)	1.18(1)	2.79(1)	12.65(3)
CL	15.66(4)	0.65(4)	1.65(4)	3.43(3)	7.46(1)

[1] see Table 5.1.

[2] ( ) numerical ranking within column.

[3] ND not determined.

(12.46-15.66 mg of N $kg^{-1}wk^{-1}$). The CG cropping system soil mineralization rate was initially greater than the Fb cropping system mineralization rate but decreased more rapidly. The CL had an initial mineralization rate of 15.66 mg $kg^{-1}wk^{-1}$ of N which decreased slowly in comparison to the other cropping systems to 6.63 mg $kg^{-1}wk^{-1}$ of N by week 20. This mineralization rate at week 20 was about 10 times as great as the next lowest cropping system. The supply of mineralizable N from the CL cropping system would be constant and greater over a longer part of the growing season.

5.3.4.2 Instantaneous Mineralization Rates

The instantaneous mineralization rate (N_o*k) at time zero was determined for each cropping system (Table 5.5). The instantaneous N mineralization rates were 7.45, 15.66, 19.85, 21.92 and 24.22 mg $kg^{-1}wk^{-1}$ of N for the Bf, CL, CB, Fb and CG cropping systems soils, respectively. Campbell et al. (1990a) reported that the instantaneous mineralization rates were more effective than N_o, k or total N in resolving treatment effects on soil organic matter quality. In the present study, however, the instantaneous mineralization rate did not reflect accurately the quantity of N mineralizable from the CL cropping system soil as by week 20 this cropping system soil was still mineralizing N at a much higher rate than the other cropping systems even though the instaneous mineralization rate was one of the lowest.

5.3.4.3 Time Required to Mineralize a Fixed Amount of N

The time required to mineralize a fixed amount of N (10, 25, 50 and 100 mg kg^{-1} of N) was calculated for each of the cropping systems (Table 5.5). Determinations could not be made for the Bf at 50 and 100 mg kg^{-1} of N and for the CB cropping system at 100 mg kg^{-1} because their N_0 values were less than those amounts (29.18 and 85.31 mg kg^{-1} of N, respectively). The ranking of the cropping systems from the least to the greatest time required to mineralize 10 or 25 mg kg^{-1} of N were the same (CG < Fb < CB < CL < Bf). The Bf cropping system required 7.61 wk to mineralize 25 mg kg^{-1} of N while the other cropping systems required between 1.18 and 1.65 wk. The Fb cropping system ranked second throughout the incubation experiment while the CL cropping system ranking changed from fourth to third when 50 mg kg^{-1} of N was to be mineralized and to first when 100 mg kg^{-1} of N was to be mineralized.

5.4 CONCLUSIONS

Differences in total organic carbon were observed among cropping systems soils, with the CG and CL cropping systems having the greatest amounts. Total organic carbon in the CL cropping system was not significantly different from the other cropping systems, however. Differences were not found in the total N, or C to N ratio among the cropping systems.

Available NH_4-N at time of sampling was very similar for all cropping systems. Available NO_3-N at time of sampling was different, with the two cropping systems in barley (CB and Bf) having the highest NO_3-N because these two cropping systems were fallowed during the 1984 growing season just prior to sampling.

The CL cropping system accumulated the largest amounts of NH_4-N during the 20-week mineralization study. The accumulation of NH_4-N was essentially complete by week 4. The greatest NO_3-N accumulation over 20 weeks was also from the CL cropping system and the least was from the Bf cropping system. The CB, Fb and CG cropping systems accumulated intermediate amounts in comparison. The accumulation of total mineral-N followed the same trends as NO_3-N.

Accumulated total mineral-N at 20 weeks was very similar to the N_o predicted by the exponential equation for all except the CL cropping system. The N_o estimated for the CL cropping system was much larger than the amount accumulated by week 20 because the mineralization process was still very active at that time and had not decreased as rapidly as those from the other cropping systems. The extreme N_o values were 29.2 and 364.2 mg kg^{-1} for the Bf and CL cropping systems. The CB, Fb and CG cropping systems had N_o values of 85.3, 121.8 and 105.9 mg , respectively. The k value of the CL cropping system was the lowest (0.043 wk^{-1}) compared to between 0.180 and 0.255 wk^{-1} for the other cropping systems.

The ranking of the cropping systems soils by their mineralization capabilities using the instantaneous (at time 0) rate of mineralization and time required to mineralize a fixed amount of N were the same up to 25 mg kg^{-1} (CG > Fb > CB > CL > Bf). The time required to mineralize 50 and 100 mg kg^{-1} of total mineral-N could not be determined for the Bf and CB cropping systems, respectively, because the N_o values calculated by the exponential equation were less than the fixed amount required. The rankings changed to CL > Fb > CG > CB > Bf when the fixed amount of 100 mg kg^{-1} total mineral-N was required because the mineralization rate of the CL cropping system soil did not decrease as rapidly as the others and the CG cropping system mineralization rate decreased more quickly in comparison to the Fb cropping system. The legume cropping system (CL) would provide greater amounts of mineral N to subsequent crops and leaching, if no crops are grown, than would the other cropping systems.

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CHAPTER 6

Net Nitrogen Mineralization from a Luvisolic Soil with Diverse Cropping Systems Amended with Plant Residues

6.1 INTRODUCTION

Crop residues replenish soil organic matter, build the nutrient reserve in soil and increase plant productivity (Janzen and Kucey 1988). Decomposition of crop residues and mineralization of nitrogen (N) is affected by soil pH, temperature, moisture, soil atmosphere O_2 and CO_2 concentration, and the amounts of inorganic nutrients (Campbell 1978, Haynes 1986). The release of N during decomposition of crop residue is also influenced by the chemical composition (cellulose, hemicellulose, waxes, lignin and protein) of residues (Parr and Papendick 1978, Swift et al. 1979, Saine et al. 1984). Lignin content (Peevy and Norman 1948, Herman et al. 1977), N concentration (Janzen and Kucey 1988) and the carbon (C) to N ratio (Herman et al. 1977, Ghidey et al. 1985) of the crop residue are important characteristics controlling the decomposition and mineralization rates.

The C to N ratios in plant residue is commonly used as an indicator of the rates of decomposition and mineralization (Parr and Papendick 1978). Plant residues with high C to N ratios decompose slowly (Parr and Papendick 1978). In a study by Janzen and Kucey (1988) the rate of decomposition of residues within a narrow range of plant species was closely related to their N content, while the C content of the plant materials did not vary greatly. It is generally accepted that the C to N ratio of organic materials has to be about 25 to 1 or less (Keeney 1984), or the N content greater than 1.5 % (Hausenbuiller 1972) for net

N mineralization to occur over the short term.

Decomposition or potential mineralization rates are not always readily predictable from the chemical composition of the materials. In a stepwise regression analysis, the release of N from a variety of plant materials was explained best by initial concentration of lignin, cellulose, hemicellulose, and N, while the C to N ratio statistically was not correlated with this variable (Muller et al. 1988). Janzen and Kucey (1988) concluded that mineralization of C, N and sulfur (S) from crop residues is primarily a function of the nutrient content rather than biochemical composition related to crop species.

Producers have observed, where cereal straw incorporation has been widely practised for twenty years or more, straw decomposes progressively more rapidly with successive seasons of incorporation (Koeller 1983). This indicates that the soil microbial biomass adapts to the added substrate. Allison and Killham (1988) studied the response of the soil microbial biomass to plant residue incorporation at three sites in Eastern Scotland and found that increases in the C to N ratio of the biomass, due to straw inputs, were greater for soils with a history of straw incorporation than for soils with no previous straw incorporation. The C to N ratio increase was attributed to the fungal component.

Mineralization and immobilization are functions of the heterotrophic biomass and occur simultaneously. The amount of net N mineralization, or net N immobilization, reflects the balances between mineralization and immobilization rates (Keeney and Gregg 1982). Knowledge of the amounts and rates of these processes under different crops and when plant residues are incorporated is essential for development of cropping systems that are less dependent on energy-intensive commercial fertilizers (Heichel and Barnes 1984, Keeney 1984).

In this study, surface Luvisolic soils from diverse cropping systems in the Peace River region of Alberta were amended with barley, fescue and fababean plant residues labelled with ^{15}N. These amended soils were incubated under controlled laboratory conditions for twenty weeks to quantify N accumulation, net N mineralization, and plant residue decomposition. The objectives were to describe: i)net mineral-N accumulation of the cropping systems soils in the presence and absence of amendments, ii)the dynamics of N during the decomposition of residues, iii)the net N immobilization and net N mineralization of cropping systems and amendments, and iv)the proportion of N mineralized from each plant residue amendment for each cropping system.

6.2 MATERIALS AND METHODS

6.2.1. Soils and Sampling

The cropping systems were first established in 1968 and consisted of:

1. continuous barley (CB),
2a. barley (Bf): 3 years barley followed by 3 years forage,
2b. forage (Fb): 3 years forage followed by 3 years barley,
3. continuous grass (CG) and
4. continuous legume (CL).

The Bf and Fb cropping systems were generally alternated every three years. The forage component of the Fb and Bf cropping system consisted of bromegrass (Bromus inermis, cv 'Carlton') and red clover (Trifolium pratense, cv 'Norlac'), the CG cropping system of bromegrass and the CL cropping system of red clover. The barley (Hordeum vulgare, cv 'Galt') was harvested as grain while the forage crops were harvested as hay. A more detailed description of the Beaverlodge Long-term Cropping System Field Experiment and its management was described in Chapter 2.

The year prior to sampling (1983) was very poor for plant growth as it was much wetter than normal. Precipitation during the 1983 growing season was 330 mm compared to the 20 year long-term mean of 203 mm and the water deficit amounted to 80 mm, much lower than the 203 mm for the 20 year normal. The excess precipitation was mainly during the months of June and July. This resulted in below average yields of barley for the CB and Bf cropping systems of 960 and 510 kg ha^{-1}, respectively. The CB cropping system and the new Bf cropping system, which came out of forage (Fb) production, were not seeded because the soil was too wet for seeding in May and June, and then because it was late, fallowed for weed control. The Fb cropping system which had been in barley (Bf) production was reseeded to a mixture of bromegrass and red clover in 1984 but was not harvested during the establishment year. The CG cropping system had been in continuous forage production since it was re-established in 1978. The CL cropping system had been re-established more recently (1983), and 1984 was the first harvest from the new seeding. Nitrogen fertilizer was applied in the spring to all cropping systems at rates of 48 kg ha^{-1} for the CB and Bf cropping systems and at 95 kg ha^{-1} for the Fb, CG and CL cropping systems because the fallowing of the CB and Bf cropping systems was unplanned.

Soil samples were taken from the Beaverlodge Long-term Cropping System Field Experiment in the late summer of 1984 from the 0-15 cm depth from each of the four replicates of the five cropping systems.

Representative surface samples were obtained by sampling with a narrow square nosed shovel at 10 random locations throughout each plot. The samples were air-dried and passed through a 2 mm stainless steel sieve and the larger organic debris was removed. Bulk samples for each cropping system were prepared by mixing equal volumes of soil from each of the four replicates.

6.2.2 Plant Residue Amendments

Barley, creeping red fescue (Festuca rubra L.) and fababean (Vicia faba L.) plant residues, labelled with ^{15}N, were obtained from field experiments at the University of Alberta's Breton Plots (100 km southwest of Edmonton). These residues were from crops grown on a Luvisolic soil and harvested as mature whole plants. The plant residues used as amendments were ground (1 mm) in a Wiley mill.

6.2.3 Nitrogen Mineralization Procedure

For each cropping system and plant residue, three replicated samples of 25 g soil, 25 g acid washed sand (0.5-1.0 mm) and 0.5 g of plant residue were mixed in 100 ml beakers and transferred to 5.5 cm plastic Buchner funnels. Samples without plant residue (non-amended) were also prepared for each cropping system. This resulted in three replictes, four amendments and five cropping systems for a total of 60 samples. A fiber-glass filter disk was placed below and on top of the soil. The top filter disk was to protect the soil sample from disaggregation and slaking during leaching (McKay and Carefoot 1981, Bonde and Rosswall 1987). The leaching solution consisted of 60 ml of 0.01 M $CaCl_2$ followed by 20 ml of minus N nutrient solution (Stanford and Smith 1972). The samples were leached at 0, 2, 4, 8, 12, 16 and 20 weeks. The leachate was collected in 250 ml filter flasks using a vacuum pump.

The leaching solution was added to the Buchner filter in 20 ml increments, allowed to equilibrate for 10 minutes before being extracted through the sample by vacuum (about 60 kPa). After the final leaching the samples were subjected to further suction for 5 minutes to remove excess leachate. The leachates were transferred to 100 ml volumetric flasks and brought to volume and part of this solution was transferred to 60 ml plastic bottles and refrigerated.

Between leachings the moist soil samples were enclosed in plastic bags to minimize drying. The samples were incubated in the dark at 30±1°C and aerated twice a week. Distilled water (2 ml) was added to the samples weekly when the time between leachings was greater than two weeks.

6.2.4 Chemical Analyses

The pH of the bulk soil samples was determined in H_2O and 0.01 M $CaCl_2$ (Peech 1965). Total C was determined by dry combustion using a Leco Carbon Determinator model CR-1. Total N was determined by the macro-Kjeldahl method (Bremmer 1965). The C to N ratio was calculated from these results. Available NO_3-N and NH_4-N were extracted from the soil samples with 0.01 M $CaCl_2$ and 2 N KCl, separately, using 5 g of sample and 50 ml of extractant. Samples were shaken for 1 hr on a reciprocal shaker at 30 cycles min^{-1} and gravity filtered. The NO_3-N and NH_4-N in the extractants and leachates were determined on a Technicon Analyzer II. Nitrate-N was determined with the Technicon Industrial Method 487-77A (Technicon 1977) and NH_4-N by the Technicon Industrial Method 98-70W (Technicon 1978). Total mineral-N was calculated as the sum of NH_4-N and NO_3-N.

Extracted total mineral-N was prepared for isotope ratio analyses using a diffusion technique (MacKown et al. 1987). Filter disks were impregnated with 10 µl 2.5 M $KHSO_4$ and suspended on a stainless steel wire above the sample solution in sealed plastic 120 ml containers (Fisher brand cat. #14-375-112A). To the sample solution consisted of 50-100 µg of N (as extractant or leachate) was added ignited MgO (approx. 0.2 g) and Devarda's alloy (approx. 0.4 g) after which it was immediately sealed and swirled to mix the contents. After 7 days, the filter disks were removed and dried over concentrated H_2SO_4 for 1 day and stored in vials. The isotope ratio analyses were determined on the filter disks and plant residue samples by combustion in a Carlo Erba 1500 Automatic N Analyzer coupled with a V.G. Isogas SIRA 10 continuous flow mass spectrophotometer.

6.2.5 Statistical Analyses

The data were analyzed using the SAS statistical package (SAS Inc. 1982). The analyses of variance (ANOVA), regression (REG) and non-linear regression (NLIN) programs were used. A protected Duncan's Multiple-Range test was used on main treatment effects from ANOVA to determine statistical differences. For ANOVA a randomized block design was used. For the NLIN the data the three replicates were averaged before the data were fitted to the exponential equation:

$$N_m = N_o \ (1-\exp^{-k*t})$$

where N_m is the cumulative net N mineralized (^{15}N) up to time t (weeks), k is the invariant rate constant (weeks^{-1}) and N_o is defined as the potentially mineralizable N pool at t=0.

6.3 RESULTS AND DISCUSSION

6.3.1 Cropping System Soil Characteristics

Selected chemical characteristics of the cropping system soils after 17 years of cropping included soil pH, total C, total N, C to N ratio and extractable NH_4-N and NO_3-N by $CaCl_2$ (0.01 M) and KCl (2 N) (Table 6.1 and 6.2). No significant differences in soil pH, N, or the C to N ratio were observed among cropping systems. The amounts of total C were the greatest for the CG and CL cropping systems with concentrations of 4.37 and 4.02 % , respectively. The total C concentrations in the CB, Bf and Fb cropping systems were 3.48, 3.36 and 3.47 %, respectively. The amount of C in the CL cropping system was not different from the other cropping systems. Cropping sytems requiring more frequent cultivation (CB, Bf and Fb) had lower amounts of organic matter. Increased cultivation has been reported by other workers to decrease the amount of organic matter in soils (Campbell et al. 1976, McGill and Hoyt 1977, Rienl 1984).

The amount of extractable NH_4-N was similar among the cropping systems. The chemical extractants $CaCl_2$ (0.01 M) and KCl (2 N) on average extracted over all cropping systems, 3.83 and 26.12 mg kg^{-1} of NH_4-N, respectively. The amount of NO_3-N extracted from each cropping system by the two methods was the same. The cropping systems in barley (CB and Bf) had significantly greater amounts of extractable NO_3-N (78 and 68 mg kg^{-1}, respectively) compared to the other three cropping systems in forage (about 10 mg kg^{-1} NO_3-N). The two cropping systems in barley (CB and Bf) had much greater amounts of NO_3-N at time of sampling than the cropping systems which had a forage crop growing due to fallowing.

Table 6.1 Characterization of soil from each cropping system as to pH, C, N, and C to N ratio.

Cropping System[1]	pH H_2O	pH $CaCl_2$	C %	N %	C/N ratio
CB	5.8	5.1	3.48 b[2]	0.30	11.6
Bf	5.8	5.0	3.36 b	0.26	12.9
Fb	6.1	5.1	3.47 b	0.28	12.4
CG	5.7	5.1	4.37a	0.32	13.7
CL	5.8	5.1	4.02ab	0.32	12.6
Significance Level	NS[3]	NS	**	NS	NS

[1] CB-continuous barley, Bf-barley/forage, Fb-forage/barley, CG-continuous grass and CL-continuous legume.

[2] means in columns followed by different letters are significantly different from each other.

[3] NS -not significant, **-significant at $P \leq 0.01$.

Table 6.2 Initial available NH_4-N and NO_3-N extracted by $CaCl_2$ and KCl for each cropping system.

Cropping System[1]	$CaCl_2$ (0.01 M) NH_4-N	$CaCl_2$ (0.01 M) NO_3-N	KCl (2 N) NH_4-N	KCl (2 N) NO_3-N
	mg kg^{-1} of soil			
CB	2.23	77.60a[2]	22.40	78.00a
Bf	4.05	68.00a	22.30	67.90a
Fb	3.69	7.43 b	27.20	7.44 b
CG	2.34	12.10 b	25.90	12.50 b
CL	6.83	10.40 b	32.80	10.10 b
Significance Level	NS[3]	**	NS	**

[1] see Table 6.1.

[2] means in columns followed by different letters are significantly different from each other.

[3] NS -not significant, **-significant at $P \leq 0.01$.

6.3.2 Plant Residue Chemical Characteristics

The ash content of the fescue residue (7.03 %) was greater than the barley (6.33 %) and fababean (6.05 %) residues (Table 6.3). The ash contents are lower than those tabulated by Hausenbuiller (1972) where young rye plant had 12.5 % ash, and alfalfa tops 10.3 %. The total C content of the creeping red fescue plant was the highest (42.0 %) which was not significantly different from the fababean (41.4 %) plant residue. The barley plant residue had a significantly lower C content (39.5 %) than the other plant residue materials. Actual C determined was considerably less than the 45 % C used as an estimate by Janzen and Kucey (1988) and Smith and Sharpley (1990). Total N, C to N ratio and % atom excess of ^{15}N was significantly different for each plant residue. Nitrogen content of the fababean (2.17 %) was less than that of the alfalfa (2.9 % N) used by (Smith and Sharpley 1990) but similar to the alfalfa listed by Hausenbuiller (1972). The cereal (oat) used by Smith and Sharpley (1990) had a similar N content as the barley plant residue. The creeping red fescue N content was a little greater than the barley because this plant had less coarse stem and little seed production. The barley amendment had a lower concentration of N than the average value of 1.6 % while the fescue at 1.35 % was nearly identical to the average for Alberta (Martin 1971). Crops harvested for hay on the whole are less mature than the crops harvested for seed as hay is harvested at early heading. The fababean residue had the lowest C to N ratio (19.1) and the barley the highest (38.5) while the fescue had an intermediate ratio (30.9 %). The % atom excess of ^{15}N for plant residues were different.

Table 6.3 Selected chemical characteristics of labelled plant residue material of barley, fescue and fababean and its % atom excess ^{15}N.

plant residue	Ash	C	N	C to N ratio	^{15}N % atom excess
	%				
barley	6.33 b[1]	39.5 b	1.03 c	38.5a	1.51996 b
fescue	7.03a	42.0a	1.36 b	30.9 b	2.50686a
fababean	6.05 b	41.4a	2.17a	19.1 c	0.99928 c
Significance level	[2] **	*	**	*	**

[1] meand within columns followed by different letters are signifiantly different according to Duncan's New Multiple Range Test.

[2] *-significant at $P \le 0.05$, **-significant at $P \le 0.01$.

Table 6.4 The amounts of mineral-N accumulated by week 20 for each cropping system and amendment and the analyses of variance summary of the main effects and interactions.

	Cropping System[1]					
Amendment	CB	Bf	Fb	CG	CL	Mean
	$mg\ kg^{-1}$ mineral-N					
none	92.2a[2]	32.4ab	121.6a	104.8a	206.6 b	111.5 b
barley	49.7 b	30.6ab	53.9 b	72.3a	172.3 c	75.8 c
fescue	41.2 b	18.9 b	20.7 c	107.1a	185.1 c	74.6 c
fababean	125.0a	66.6a	134.8a	71.0a	300.3a	139.5a
Mean	77.0 B	37.1 C	82.8 B	88.8 B	216.1A	

Source of Variation	df	Summary of Analyses of Variance mean square	Pr.>F[3]
Rep	2	1107.7	0.0239
Cropping System(CS)	4	55129.0	0.0001
Error a	8	150.9	
Amendment(A)	3	14638.6	0.0001
CS*A	12	2831.4	0.0001
Error b	30	435.6	

[1] see Table 6.1.

[2] means within columns followed by lowercase letters and within row followed by uppercase letters are significantly different ($P \le 0.05$) according to Duncan's New Multiple Range test.

[3] the significance probability associated with the F statistic.

6.3.3 Accumulation of Mineral-N by Week 20

There was a highly significant difference among the cropping systems and amendments for total mineral-N accumulated by week 20. The interaction of cropping system and amendment was also significant (Table 6.4). The least mineral N, averaged over all amendments, was accumulated by the Bf cropping system which differed from all other cropping systems. This result could not be explained completely from the organic matter and N content of this soil even though this cropping system had the lowest amount of total N. The fallowing of this soil during the 1984 growing season has resulted in the depletion of easily mineralizable being depleted. The highest amount of mineral N was accumulated from the CL cropping system which was significantly different from all other cropping systems. This result could be explained by the fact that this cropping system soil was growing a legume which has a higher N content than the cropping systems growing barley, grass or a grass dominated grass-clover mixture. No significant differences in mineral N accumulation were observed among the CB, Fb and CG cropping systems which were intermediate between the Bf and CL cropping systems.

The mean across all cropping systems for each amendment indicated that the least N accumulated from the barley and fescue amended soils, with no difference between them. The non-amended soil accumulated an intermediate amount and was different from the other amendments. The fababean amended cropping system soils had the highest accumulation of mineralizable N and was different from all other amendments. Addition of plant residues to the soil can increase or decrease N accumulation; with barley or fescue accumulated N decreased to 70 % of the non-amended soil because of immobilization, while the addition of fababean resulted in net mineralization increasing to 125 % over a 20 week incubation period when compared to non-amended cropping system soils.

Differences in N accumulation due to the amendment were observed within each cropping system except the CG cropping system. For the CB cropping system the fababean amendment resulted in the greatest accumulation of mineral-N (125.0 mg kg^{-1} mineral-N) but this was not different from the non-amended soil (92.2 mg kg^{-1} mineral-N). The barley and fescue amendments to the CB cropping system soil resulted in significantly lower amounts of mineral-N accumulation (49.7 and 41.2 mg kg^{-1}) compared to fababean and non-amended soils. Similar trends among the amendments were observed for the Bf and Fb cropping systems soils. The only significant difference for the Bf cropping system was between the fababean amendment which accumulated the highest mineal N (66.6 mg kg^{-1}) and fescue the lowest (18.9 mg kg^{-1}). Addition of the fababean amendment to the Bf cropping system soil resulted in the accumulation of twice as much mineral-N as for the non-amended soil. This increase was greater in proportion than for any other cropping system. The Fb cropping system soil showed no difference between the fababean and non-amended cropping system soils (134.8 and 121.6 mg kg^{-1} mineral-N). The barley and fescue amendments for this cropping system were significantly different from each other and the other amendments (53.9 and 20.7 mg kg^{-1} mineral-N, respectively).

There were no differences in total mineral-N accumulation from the amendments added to the CG cropping system soil. This was partly because of marked variability of the replicates, which was unexpected as replicate sub-samples were obtained from the same bulked sample. The standard deviation of the replicates within each amendment (none, barley, fescue and fababean) at 20 weeks was 32.4 33.9, 16.1 and 30.6 mg kg^{-1}, respectively. Addition of the fescue amendment to this cropping system resulted in a similar level of mineral-N accumulation (107.1 mg kg^{-1} mineral-N) compared to the non-amended soil (104.8 mg kg^{-1} mineral-N). The fababean amendment resulted in mineral-N accumulation that was lower (71.0 mg kg^{-1} mineral-N) but similar to the barley amended soil (72.3 mg kg^{-1}). This was an indication that the CG cropping soil was "conditioned" to decompose the fescue amendment even though the fababean amendment had a more favourable N content and C to N ratio.

The CL cropping system amended with fababean had a greater accumulation of total mineral-N (300.3 mg kg^{-1} N) at week 20 than the non-amended soil (206.6 mg kg^{-1} mineral-N). The barley and fescue amendments to the CL cropping system soil accumulated significantly lower amounts (172.3 and 185.1 mg kg^{-1} mineral-N). Addition of barley or fescue amendments resulted in decreased accumulated N compared to the non-amended soil over a 20 week period but the amounts from the barely and fescue were still considerably greater than any accumulated N from the other cropping systems because of the more favourble C to N ratio of the CL cropping system soil resulting in more available N for the active biomass.

6.3.4 Nitrogen Immobilization and Mineralization

The difference in amount of net N mineralized, between the non-amended and amended soils, was plotted over time (Fig. 6.1). In this plot, negative net mineral-N accumulation represents net

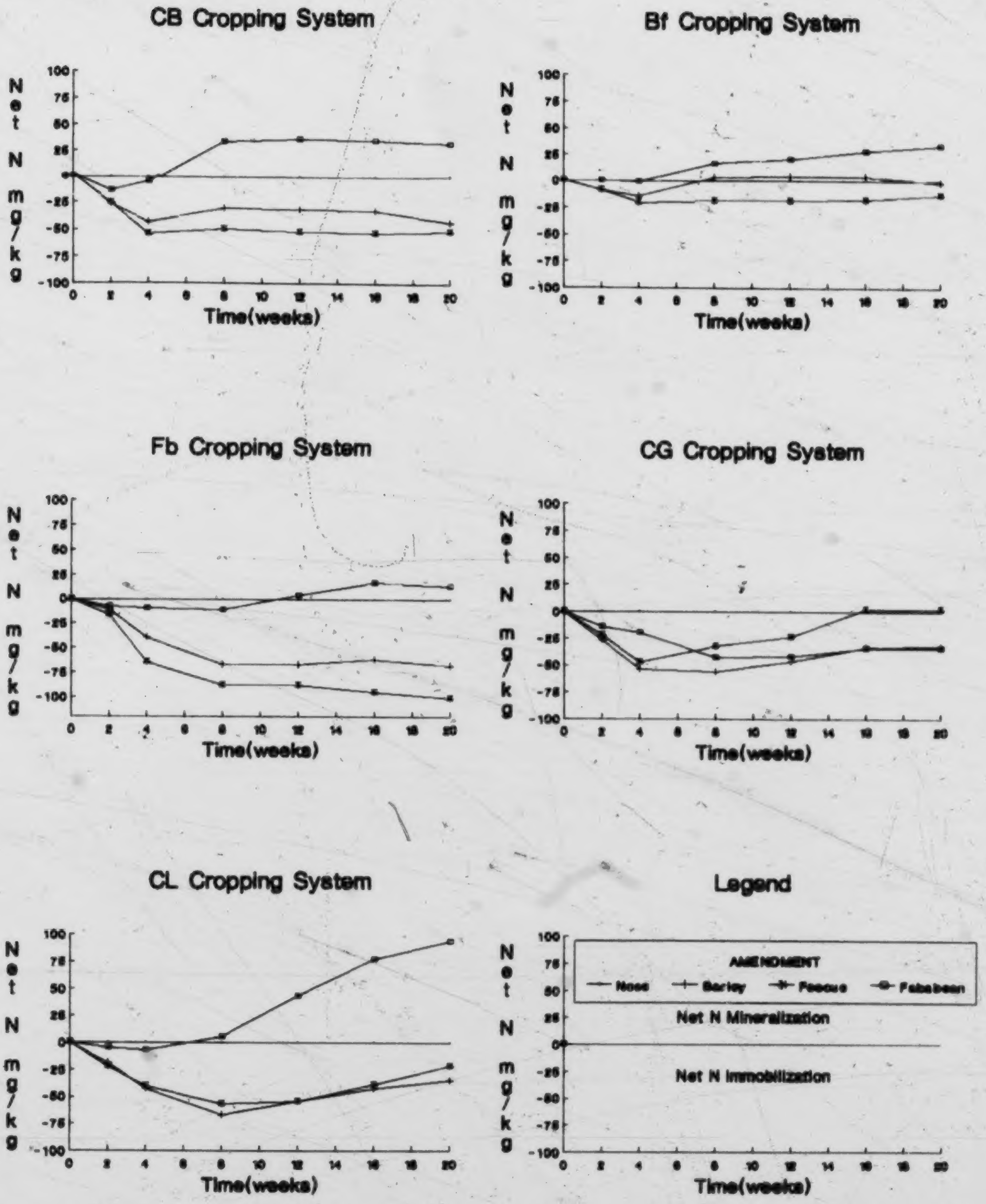

Fig. 6.1 Net N immobilization and net N mineralization curves for each cropping system soil and amendment. Curves determined from the difference in mineral N accumulated between amended and non-amended soil. Horizontal line at ordinate value of 0 represents net N mineralization for the non-amended soil.

immobilization while positive mineral-N accumulation represents net N mineralization.

The fababean amendment resulted in net mineralization for the all cropping systems except the CG. Net N mineralization with this amendment occurred by 8, 4, 12 and 8 weeks for the CB, Bf, Fb and CL cropping systems, respectively. For the CG cropping system the fababean amendment did not result in net N mineralization when compared to the non-amended soil. The only other cases of net mineralization occurred from the barley amendment to the Bf cropping system after 8 weeks and the fescue amendment to the CG cropping system after 16 weeks and these accumulations were very small. Net N immobilization was greater from the fescue than barley amendment for the CB, Bf and Fb cropping systems even though the fescue had a higher N content. The N of the fescue is probably less available because of structural or biochemical differences. This observation was not in agreement with Janzen and Kucey (1988) who observed that the decomposition or mineralization of crop residues was more dependent on nutrient content, such as N, than biochemical composition. In the CL cropping system both the barley and fescue amendments immobilized nearly identical amounts of N over the entire incubation period by contrast. The barley and fababean amendments in the CG cropping system immobilized similar amounts of N. Plant residues (cornstalks, soybean, alfalfa and saw-dust) added to five Iowa soils resulted in net N mineralization from the beginning of the experiment only for the alfalfa amendment (Chae and Tabatabai 1986). Soybean residue resulted in a delay in net N mineralization to between week 10 and 18 depending on the soil type while cornstalk and sawdust materials caused net immobilization for the entire incubation period (26 weeks). Addition of organic residues to soils can be used to increase or decrease the amount of N mineralization over a set period of time within a cropping system. Organic materials with low N contents or wide C to N ratios will usually result in net N immobilization for a longer period of time than materials having a high N content and narrower C to N ratio.

6.3.5 Proportions of N Mineralized from Amendments over Time

The percent N mineralized from the plant residue calculated by difference between initial ^{15}N and ^{15}N accumulated in the leachate over time, increased for all amendments and cropping systems (Figure 6.2). The relationship generally followed similar trends observed for total mineral-N accumulated from the amended soils.

The greatest proportion of residue N mineralized occurred from the fababean amended cropping system soils, except for the CG cropping system. The CG cropping system soil initially had a higher percentage of N mineralizing from the fababean amendment but its rate decreased more rapidly over time in comparison to the barley and fescue amendments resulting in a lower accumulation of mineralized N by week 12. The fescue amendment on average had the least proportion of its N mineralized when added to the CB, Bf, Fb and CL cropping system soils.

The percent of the amendment mineralized in the Janzen and Kucey (1988) study was dependent on the species and N level. These authors observed that by week 4 of the incubation, 0.71, 2.76 and 13.70 % of the low, moderate and high N status lentil amendment repectively, had mineralized. The high amount mineralized from the high N status lentil amendment could be due to soluble N being present in the amendment leaching and not actual mineralization of organic N. For the high N status wheat and rape plant amendments 3.99 and 0.53 % of the residue had mineralized. In the present study similar amounts of the plant amendment were mineralized by week four with 2.6, 0.5 and 5.2 % for the barley, fescue and fababean amendments averaged over all cropping systems, respectively.

6.3.6 Percent ^{15}N Mineralized from Amendments by Week 20

The percent of the plant residue mineralized by week 20 was strongly influenced by the cropping system and amendment. A significant interaction between cropping system and amendment was also observed (Table 6.5).

The CL cropping system mineralized the greatest amount of N from the added amendments (24.8 %) by week 20, which was significantly different from all other cropping systems. The amount of N mineralized from the CB, Fb and CG cropping systems was considerably less (8.7, 7.5 and 7.3 %, respectively) in comparison to that of the CL cropping system while that of the Bf cropping system was the least (4.4 %). The lower amount of N mineralized from the Bf cropping system soil was because this cropping system had been fallowed and easily mineralizable had been utilized resulting in a less biological active soil.

The proportions of N mineralized from each of the amendments were different. The fababean amendment on average over all cropping systems mineralized the greatest proportion of N (14.0 %). The barley amendment mineralized 10.5 % of the total N while the fescue amendment mineralized 7.1 %. Even though the fescue plant residue had a higher N content and lower C to N ratio than the barley, the fescue decomposed more slowly when averaged across all cropping system soils. The incorporation of plant residue materials with high N contents such as

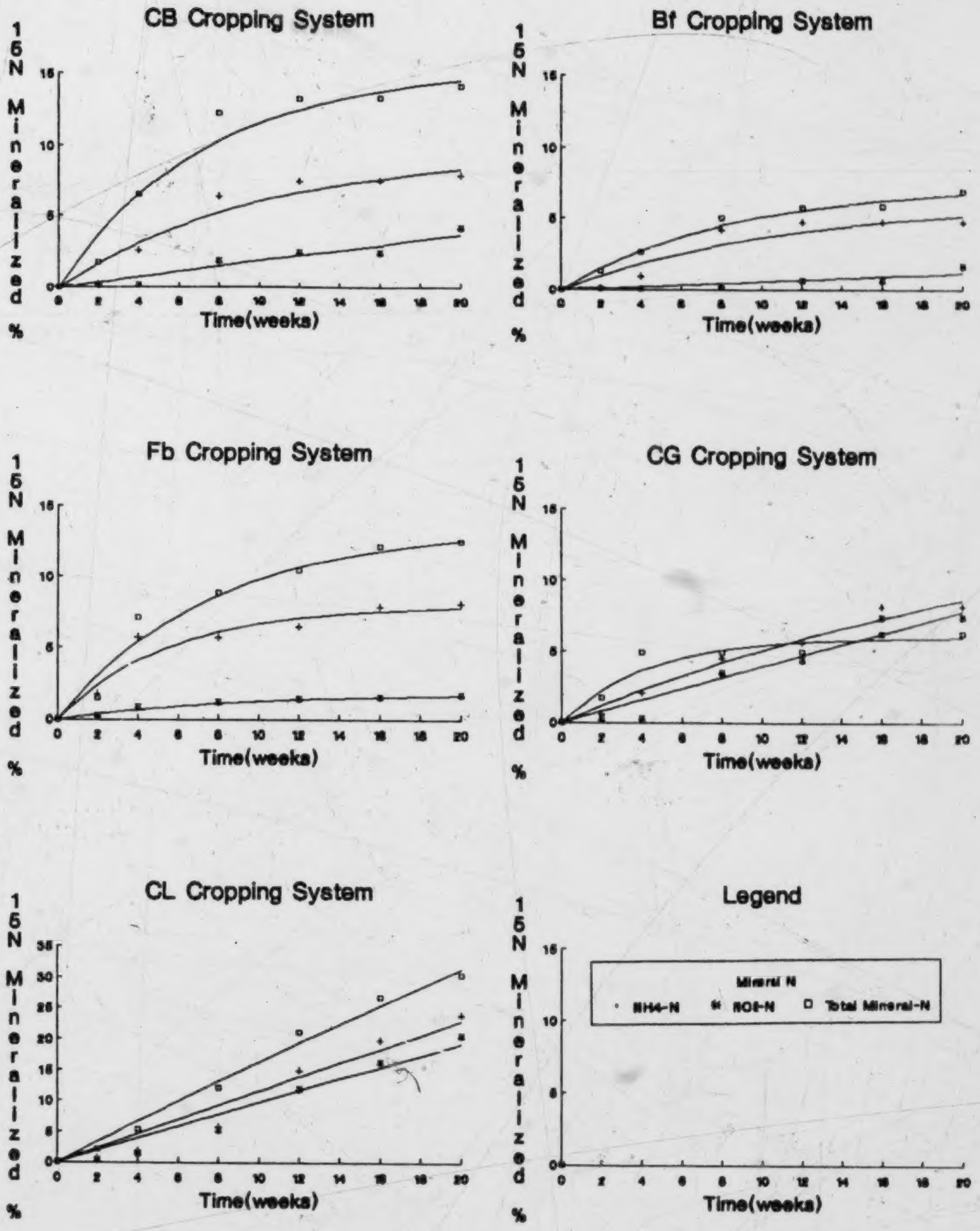

Fig. 6.2 Proportion of ^{15}N labelled plant residue mineralized over incubation period for each cropping system and plant residue amendment (note that ordinate maximum of CL cropping system is 35 compared to 15 % for the other cropping systems).

Table 6.5 Percent of ^{15}N labelled plant residue mineralized by week 20 from cropping system soils amended and incubated with barley, fescue and fababean.

	Cropping system					
Amendment	CB[1]	Bf	Fb	CG	CL	Mean
			% of initial ^{15}N			
barley	7.8 b	4.6 b	8.2 b	8.2a	23.7 b	10.5 b[2]
fescue	4.2 c	1.7 c	1.7 c	7.4a	20.5 b	7.1 c
fababean	14.1a	6.7a	12.5a	6.3a	30.2a	14.0a
Mean	8.7 B	4.4 C	7.5 B	7.3 B	24.8A	

Summary of Analyses of Variance

Source of Variation	df	Mean Square	Pr>F[3]
Rep	2	22.9	0.0337
Cropping System(CS)	4	598.44	0.0001
Error a	8	4.14	
Amendment(A)	3	177.09	0.0001
CS*A	12	20.56	0.0001
Error b	30	5.15	

[1] see Table 6.1.

[2] means of columns followed by lowercase and row followed by uppercase letters are significantly different ($P \leq 0.05$) from each other using Duncan's New Multiple Range test.

[3] the significance probability associated with the F statistic.

fababean results in a more rapid decomposition and increased release of N to the soil system from the amendment than when barley or fescue plant residues are added.

There was a similar trend in the proportion of plant residue mineralized from the different amendments within each of the cropping systems except for the CG cropping system. In the CB, Bf, Fb and CL cropping system a greater proportion of the fababean amendment was mineralized. For the CB, Bf, and Fb cropping systems the percent N mineralized from the barley amendment was intermediate and different from the fababean and fescue amendments. The fescue amendment had the lowest proportion of its N mineralized in the soil of the CB, Bf and Fb cropping systems. There were no differences between the barley and fescue amendments when added to the CL cropping system. There were also no significant differences in the total amount of N mineralized by week 20 from the three plant residue amendments to the CG cropping system.

6.4 CONCLUSIONS

Net total mineral-N accumulation increased over time for all cropping systems and amendments. The Bf cropping system on average accumulated the least and the CL cropping system the most total mineral-N. Total N in the soil of the Bf cropping system was the lowest but it was not significantly different from the others. Differences in N accumulation for the cropping system soils could not be explained by the C to N ratios which were similar among the cropping systems.

The N accumulation within each cropping system was the greatest for the fababean amendment except for the CG cropping system. For the CG cropping system the fescue amendment resulted in the greatest accumulation of N but this was not significantly different from other cropping systems due to high variability within the replicates. Amending cropping systems with barley resulted in greater accumulation of N compared to fescue for the CB, Bf, and Fb cropping systems while for the CL cropping system it was similar.

Net N immobilization and net N mineralization for the amended cropping system soils were different. The fababean amendment resulted in net mineralization from each cropping system except for CG. Net N mineralization would be expected as this plant residue had a C to N ratio less than 25 and a N content greater than 1.5 %. The net N immobilization due to the fababean amendment to the CG cropping system could not be explained. The only other cropping systems and amendments that had net N mineralization were the Bf and CG cropping systems with barley and fescue as amendments, respectively, which were small and occurred late during incubation period.

The proportion of accumulated N derived from each amendment varied with the cropping system. Averaged over all 3 amendments, the Bf cropping system accumulated <5 % and the CL cropping system close to 25 % of its total mineral-N from the amendments.

The fababean amendment decomposed more rapidly and contributed a larger proportion of N to the accumulated total mineral-N for all cropping systems except the CG cropping system. The fescue amendment on average contributed a smaller proportion of N to the total accumulated amount for all cropping systems except the CG cropping system. This was especially apparent in the CB, Bf and Fb cropping systems where the fescue amendment contributed significantly less and decomposed at a slower rate.

The type of plant residue and the cropping system to which it is added has an influence on the rate of mineralization and therefore how quickly it decomposes. Generally, except for the CG cropping system, the addition of the fababean plant residue resulted in increased net N mineralization. A greater proportion of labelled barley residue was mineralized over 20 weeks when added to cropping systems growing barley, either continuous or in a rotation (CB, Bf and Fb), than the CG and CL cropping systems which did not grow barley. In the CG cropping system no significant differences were observed among the plant residues but the fababean as well as the barley plant residue resulted in net N immobilization but this was not the case for the grass plant residue.

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CHAPTER 7

Synthesis

The two long-term crop rotations studies on Luvisolic soils are the Breton Plots of the University of Alberta, initiated in 1929, and the Beaverlodge Long-term Cropping System Field Experiment established in 1968. This study used the Beaverlodge Long-term Cropping System Field Experiment and investigated the impact of diverse cropping systems on the physical, chemical and biological properties of cropping system soils. The cropping systems studied consisted of: 1) continuous barley (CB), 2a) 3 y of barley followed by 3 y of grass/legume (Bf), 2b) 3 y grass/legume followed by 3 y barley (Fb), 3) continuous grass (CG), and 4) continuous legume (CL).

Long-term cropping practices affect soil structure. Changes in soil structure affect soil bulk density, porosity, infiltration, water storage, water transport and run-off. Improvement of aggregation and movement of water into and through the soils were observed for cropping systems under forage (CG and CL). Bulk density of the 0-15 and 15-30 cm depth intervals of the CL cropping system was lower than other cropping systems. Saturated hydraulic conductivity was improved significantly for the 0-15 cm depth intervals for the CG and CL cropping systems and the 15-30 cm depth interval of the CL cropping system. Similarly, the CG cropping system had the highest infiltration rate. By contrast the CB, Bf, and Fb cropping systems had lower saturated hydraulic conductivity and infiltration rates. Wet sieving indicated that the CG cropping system had more large water stable aggegates and the CG and CL cropping systems had more stable aggregates than the other cropping systems. Thus soils in continuous forage production had improved aeration, reduced puddling of the surface horizon, less crusting, fewer tillage problems, an increased water reserve and a deeper rooting zone.

Long-term cropping practices also affect soil organic matter content. Soil organic matter affects supply of nutrients for crop growth. In this study, the amount of N mineralized in a laboratory experiment was used as an index of the long-term effect of crop rotations. The CL cropping system mineralized about two times as much N (207 mg kg-1) compared to the average of the other four cropping systems during a 20 wk laboratory incubation. The exponential model described the mineralization curves for all soils except for CL. Mineralization rates for the cropping system soils decreased with time, however, the rate for the CG cropping system decreased more slowly resulting in a steadier supply of mineral N.

Mineralization rates of soils from different cropping systems were affected by the addition of different plant residue amendments. The fababean amendment resulted in net mineralization by week 12 in all cropping systems except CG. The grass amendment added to the soil from CG tended to accumulate a larger amount of mineral N than all other cropping systems. Cropping systems with continuous barley or barley as a part of rotation mineralized a greater proportion of N from the barley than fescue residue indicating that some "conditioning" had occurred although the fescue residue had a narrower C to N ratio. This study indicated that the type of plant residue and cropping history influenced the rate of decomposition and affected the amount of N mineralized. This observation may aid in regulating the amount and the rate of N mineralization for subsequent crops.

In the Peace River Region Luvisolic soils are often subjected to tillage, seeding and harvesting operations when too wet because of unfavourable weather and hydrology. It is these conditions and the weak structure of the Luvisolic soils that can result in soil degradation. Cropping systems that incorporate organic matter into these soils produce a more stable surface structure and more mineralizable nutrients. This can be accomplished by the use of forage crops in rotations or newer technologies such as minimum till or no-till. The use of forage crops, especially deep rooted ones, have an added positive effect on the dense B horizon of these soils as was observed from the higher saturated hydraulic conductivity and infiltration rates.

A principal objective of any cropping system or soil management program is sustained profitable agricultural production as producers are determined to earn the highest possible net return to their investments. Factors considered when making cropping system choices include: potential gross revenue, cost of resources and services used in production, level of risk involved and long-term effects on soil productivity and economic returns. In this study only some of the long-term effects of the different cropping systems on soils were assessed and the economic question was not addressed even though very important.

CHAPTER 8

APPENDICES

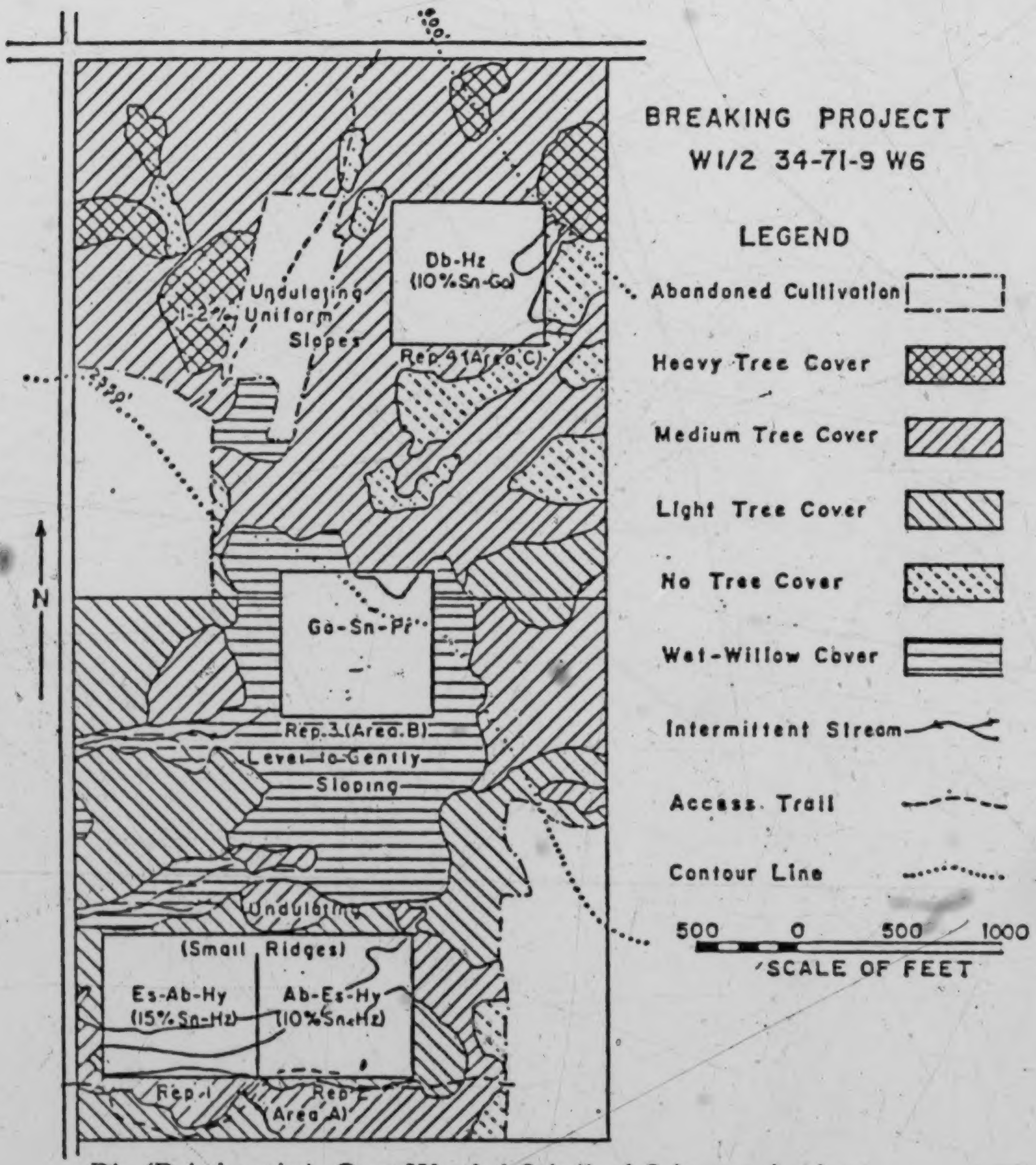
Appendix 8.1 Soil Descriptions and Plot Area Information of the Beaverlodge Long-term Cropping System Experiment.

8.1.1 Soil Descriptions and Plot Information

The area used for the Beaverlodge Long-term Cropping System Field Experiment Experiment was soil surveyed as part of the Beaverlodge and Blueberry Mountain sheets (Odynsky et al. 1961). A special soils report of the study area was conducted for the Beaverlodge Breaking Project by the Research Council of Alberta (1956). This report could not be located at the Beaverlodge Research Station, Agriculture Canada Soil Survey Unit (Edmonton), or the Research Council of Alberta library in Edmonton. Some of the results from this report were included in a research paper dealing with the effects of methods used to break virgin Wooded (Luvisolic) soils on the yields of wheat and flax (Hennig 1965). Replicates 1 and 2 from the Beaverlodge Breaking Project were used for the establishment of the Beaverlodge Cropping System Experiment in 1968.

Figure 1 of the study conducted by Hennig (1965) was used to create Figure 8.1 for this appendix and designates the predominant soil types and topography for the Beaverlodge Long-term Cropping System Experiment. The experimental area was mapped as having a complex of three soil series, Albright, Esher and Hythe with a minor inclusion (<10 %) of Snipe and Hazelmere. The detailed descriptions of these soils can be found in the soil survey of the Beaverlodge and Blueberry Mountain sheets (Odynsky et al. 1961).

The soils were developed on lacustro-till and glacial-lacustrine materials and the parent material deposits consist of well sorted, gray to dark grayish brown clay that has few stones, numerous gypsum crystals and may be derived largely from the products of the Smoky River shales. These deposits are quite uniform and could have been laid down in a glacial lake. The surface horizon textures of these soils are loam to clay loam and the internal drainage varies from poor to moderately imperfect. Except, for the Snipe, these soils were considered to be very suitable for cultivated agriculture. Special concerns were noted in the descriptions and included the requirement of organic matter maintenance, improved permeability and structure of subsoils and prevention of soil loss by water erosion (Odynsky 1961).


BREAKING PROJECT
W1/2 34-71-9 W6
LEGEND
Abandoned Cultivation
Heavy Tree Cover
Medium Tree Cover
Light Tree Cover
No Tree Cover
Wet-Willow Cover
Intermittent Stream
Access Trail
Contour Line
500
0
500
1000
SCALE OF FEET
N
Db-Hz
(10% Sn-Go)
Undulating
1-2% Uniform
Slopes
Rep.4 (Area C)
Go-Sn-Pr
Rep.3 (Area B)
Level to Gently
Sloping
Undulating
(Small Ridges)
Es-Ab-Hy
(15% Sn-Hz)
Ab-Es-Hy
(10% Sn-Hz)
Rep.1
Rep.2
(Area A)

Db	(Debolt series), Gray Wooded Solodized Solonetz, clay loam
Hz	(Hazelmere series), Gray Wooded Solod, loam and clay loam
Sn	(Snipe series), Low Humic Eluviated Gleysol, loam and clay loam
Go	(Goose series), Orthic Meadow, silty clay loam and clay
Pr	(Prestville series), Peaty meadow, silty clay loam and clay
Ab	(Albright series), Dark Gray Solod, loam and clay loam
Hy	(Hythe series), Dark Gray Wooded, sandy loam and loam
Es	(Esher series), Dark Gray Solod, loam and clay loam

Figure 8.1 Original tree cover, topography classes, location of four replicates from the Breaking Project to study land clearing effects on following crops and the prominant soil types of the study area. Only replicates 1 and 2 were used for the the present day Beaverlodge Long-term Cropping System Field Experiment (from Hennig 1965, Figure 1).

8.1.2 Soil Descriptions from Odynsky et al.(1961)

8.1.2.1 Esher series - Gray Solod, loam and clay loam.

Profile Description: Esher soils are distinguished by their well developed dark colored Ah horizon that is usually 5-15 cm thick. The B horizon is often quite compact but will break fairly readily into fine blocky to nuciform aggregates. The following is typical of an Esher soil profile:

Horizon	Depth cm	Description
	2-0	Dark brown (10YR 3/3 moist) to very dark grayish brown (10YR 3/2 moist) leaf litter. pH 7.3.
Ah	0-10	Dark brown (10YR 3/3 moist) to brown (10YR 4/3 moist) silt loam to clay loam, weak prismatic, weak nuciform, friable. pH 5.7.
Ae	10-17	Light yellowish brown (10YR 6/4 moist) silt loam to loam, platy in the upper portion, coarse platy and nuciform in lower portion, friable. pH 5.5.
AB	17-25	Light yellowish brown (10YR 6/4 moist) to yellowish brown (10YR 5/4 moist) silt loam to silty clay loam, nuciform, vesicular, friable. Resemble the tops of old columns. pH 4.9.
Bt1	25-38	Dark yellowish brown (10YR 4/4 moist) silty clay to clay, columnar, blocky to nuciform, very firm cleavage faces stained dark brown (10YR 3/3 moist). pH 4.7.
Bt2	38-53	Dark yellowish brown (10YR 4/4 moist) to dark brown (10YR 3/3 moist) clay, weak columnar to massive, blocky, very firm. pH 5.0.
BC	53-78	Grayish brown (10YR 5/2 moist) to dark gray (10YR 4/1 moist) clay, weak massive, blocky to nuciform, firm. Occasional strata of stony, yellowish brown (10YR 5/4 moist) clay loam. pH 5.9.
Ck	75-78	Grayish brown (10YR 5/2 moist) to dark gray (10YR 4/1 moist) clay loam to clay. Moderate lime content. pH 7.9.
C	78+	Dark gray (10YR 4/1 moist) clay with occasional strata of grayish brown (10YR 5/2 moist) to yellowish brown (10YR 5/4 moist) clay loam, in which stones and salt pockets are of common occurrence. pH 8.1.

8.1.2.2 Albright series - Gray Solod, loam and clay loam.

Profile Description: Albright soils differ from the Esher soils in having a somewhat browner solum and a more friable B horizon. While Albright soils usually have more stones, the stones do not occur in sufficient numbers to materially affect agricultural development. The following is a description of a typical Albright soil profile:

Horizon	Depth cm	Description
Ah	0-13	Very dark grayish brown (10YR 3/2 moist) in upper portion grading to brown (10YR 4/3 moist) in the lower portion, silt loam to silty clay loam, weak fine granular, friable. pH 6.4.
Ae	13-18	Light yellowish brown (10YR 6/4 moist) silt loam, fine platy, friable pH 6.1.
AB	18-21	Yellowish brown (10YR 5/4 moist) silty clay loam, coarse platy, nuciform, vesiculate, friable. pH 6.1.
Bt1(Bntj)	21-39	Grayish brown (10YR 5/2 moist) to brown (10 YR 5/3 moist) silty clay loam to clay, weak columnar, nuciform, firm. pH 5.4.
Bt2	39-52	Dark grayish brown (10YR 4/2 moist) to dark brown (10YR 3/3 moist) clay, blocky, very firm. pH 5.1.
BC	52-65	Dark grayish brown (10YR 4/2 moist) and dark gray (10YR 4/1 moist) layers or patches, clay, blocky, firm, occasional small stones. pH 6.4.
C	65+	Dark gray (10YR 4/1 moist) clay with lenses or strata of yellowish brown (10YR 5/4 moist) silt loam or sandy clay loam that are frequently stony. Lime accumulations occur in the upper portion of this horizon while salt accumulations occur at depths of 85 to 90 cm. pH 7.9.

8.1.2.3 Hythe series - Dark Gray Luvisol, sandy loam and loam.

Profile Description: These soils have a well developed dark colored Ah horizon. The remaining portion of the solum is brownish in color, and has occasional stones and sandstone fragments. Dark colored organic staining is common to many of the cleavage faces in the lower portion of the solum. Generally, Hythe soils are somewhat coarser in texture. The following is typical of a Hythe soil profile:

Horizon	Depth cm	Description
L-H	0-3	Very dark brown (10YR 2/2 moist) leaf litter. pH 6.8.
Ah	0-8	Very dark grayish brown (10YR 3/2 moist) loam, platy, fine granular, friable. pH 6.4.
Ae	8-16	Brown (10YR 5/3 moist) grading to pale brown (10YR 6/3 moist) in lower portion, sandy loam, platy, friable. pH 5.5.
AB	16-19	Pale brown (10YR 6/3 moist) loam, nuciform, vesicular, friable. pH 5.3.
Bt1	19-32	Brown (10YR 5/3 moist) clay loam, weak columnar, nuciform, firm. pH 5.0.
Bt2	32-52	Brown (10YR 5/3 moist) to yellowish brown (10YR 5/4) moist) clay loam, nuciform to blocky, firm. Occasional dark gray (10YR 4/1) moist) staining on cleavage faces. pH 5.3.
BC	52-70	Yellowish brown (10YR 5/4 moist) to dark yellowish brown (10YR 4/4 moist) sandy clay loam, blocky to coarse blocky, firm. Occasional dark gray (10YR 4/1 moist) staining on cleavage faces. pH 5.7.
C	70-95	Yellowish brown (10YR 5/4 moist) to dark yellowish brown (10YR 4/4 moist) sandy clay loam, coarse blocky. Occasional stones, and sandstone fragments occur in this till. pH 6.2.
IIC	95	Dark grayish brown (10YR 4/2 moist) clay, below surface nuciform, firm. Lime occurs in small pockets. pH 7.6.

8.1.2.4 Snipe series - Luvic Gleysol, loam and clay loam

Profile Description: Snipe soils are distinquished by a peaty horizon, and by a fairly thick, somewhat iron stained, Ae horizon. The rusty, iron staining is not usually apparent in the darker colored B horizon. The following description is typical of a Snipe soil profile:

Horizon	Depth cm	Description
L	12-2	Dark brown (10YR 4/3 to 3/3 moist) peat. May be absent in burned over areas. pH 5.9.
H	2-0	Very dark brown (10YR 2/2 moist) decomposed peat. pH 6.2.
Ah	0-2	Dark grayish brown (10YR 4/2 moist) loam to silt loam, weak granular, friable. pH 5.6.
Aeg	2-15	Light gray (10YR 7/2 moist) to very pale brown (10YR 7/4 moist) very fine sandy loam to silt loam, platy, fiable, with some brownish colored (10YR 5/4 moist) mottling. pH 5.2.
ABg	15-20	Gray (10YR 5/1 moist) to dark gray (10YR 4/1 moist) clay, nuciform, firm. pH 4.9.
Btg	20-48	Gray (10YR 5/1 moist) to dark gray (10YR 4/1 moist) clay, fine blocky, firm, with waxy of glazed appearance when dry. pH 5.3.
BCg	48-76	Dark gray (10YR 4/1 moist) clay, nuciform, friable. pH 6.9.
Ck	76-80	Grayish brown (10YR 5/2 moist) to dark greyish brown (10YR 4/2 moist) clay loam to clay, blocky, friable. pH 7.3.
C	80+	Grayish brown (10YR 5/2 moist) to yellowish brown (10YR 5/4 moist) clay loam, till. pH 7.5.

8.1.2.5 **Hazelmere series** - Gray Luvisol, loam and clay loam.

Profile Description: Hazelmere soils have a relatively thin organic surface horizon, may have a thin Ah horizon, and have a prominent leached Ae horizon that is usually about 10 cm thick. The remainder of the solum is mainly dark grayish brown to dark yellowish brown in color, is medium to fine textured, and the darker colored B horizon is fairly compact and firm. The following description is typical of a Hazelmere soil profile:

Horizon	Depth cm	Description
L-H	0-2	Dark brown (10YR 3/3 moist) to very dark grayish brown (10YR 3/2 moist) leaf litter. pH 6.4.
Ah	0-3	Dark grayish brown (10YR 4/2 moist) to dark gray (10YR 4/1 moist) loam to clay loam weak granular, friable. This horizon may be absent. pH 5.9
Ae	3-11	Light yellowish brown (10YR 6/4 moist) very fine sandy loam to silt loam, platy grading to coarse platy in the lower portion, friable. pH 5.7.
AB1	11-16	Light yellowish brown (10YR 6/4 moist) to grayish brown (10YR 5/2 moist) silt loam to silty clay loam, coarse platy to coarse nuciform, vesicular, friable. Rusty stains or mottles are common in this horizon and in the lower portion of the preceding horizon. pH 5.6.
AB2	16-21	Grayish brown (10YR 5/2 moist) silty clay loam, nuciform, friable to firm. pH 5.5.
Bt1(Btnj)	21-34	Dark grayish brown (10YR 4/2 moist) clay, weak columnar, nuciform to fine nuciform, very firm. pH 5.4.
Bt2	34-50	Dark grayish brown (10YR 4/2 moist) to dark brown (10YR 4/3 moist) clay, nuciform to blocky, very firm. pH 5.9.
BC	70-88	Dark yellowish brown (10YR 4/4 moist) with occasional pockets or strata of dark gray (10YR 4/1 moist) to dark grayish brown (10YR 4/2 moist) clay to sandy clay, fine nuciform, firm. pH 7.0.
C	88+	Strata of gray (10YR 5/1 moist) clay and yellowish brown (10YR 4/4 moist) sandy clay loam in which small stones are of common occurrence. The strata are of varying thickness and lime accumulations are found in the upper portion of this horizon. pH 7.7.

8.1.3 References

Hennig, A.M.F. 1965. The effect of methods used to break virgin wooded soils on the yields of wheat and flax. Can. J. Soil Sci 45:281-288.

Odynsky, Wm., J.D. Lindsay, S.W. Reeder and A. Wynnyk. 1961. Reconnaissance soil survey of the Beaverlodge and Blueberry Mountain sheets. Research Council of Alberta, Report No. 81.

Research Council of Alberta, Edmonton, AB. 1956. Soil report of the Beaverlodge Breaking Project, 1956.[1]

[1] Report missing.

Appendix 8.2 Climatic and weather data (1968-1987).

Table 8.1 Temperature and precipitation data for the Beaverlodge metereological site for the years 1968 to 1989.

Year	Annual	Apr	May	June	July	Aug	GS[1]
			Temperature (°C)				
1968		2.7	8.7	11.9	14.9	12.4	10.1
1969		4.1	10.0	13.8	14.5	13.3	11.1
1970		3.6	8.8	14.9	15.6	15.5	11.7
1971		3.6	11.4	13.5	15.6	16.0	12.0
1972		0.1	11.1	13.9	13.7	15.2	10.8
1973		3.6	10.7	12.3	14.8	12.7	10.8
1974		3.0	7.6	13.2	13.4	13.5	10.1
1975		0.8	9.3	12.7	17.1	12.1	10.4
1976		5.2	9.9	11.2	14.2	14.3	11.0
1977		6.4	9.6	13.2	13.8	13.5	11.3
1978		4.0	8.1	14.8	16.0	13.7	11.3
1979		-0.1	7.2	12.8	16.1	15.3	10.3
1980		7.3	10.7	14.3	15.0	12.9	12.0
1981		2.1	11.8	12.0	16.8	18.0	12.1
1982		-1.1	9.0	15.5	16.2	11.8	12.7
1983		4.4	10.4	13.1	15.0	15.0	11.6
1984		5.4	7.8	12.9	15.7	15.3	11.4
1985		3.8	10.9	12.8	16.8	14.1	11.7
1986		2.6	9.4	13.6	15.1	15.3	11.2
1987		6.3	10.6	14.9	16.0	12.4	12.0
Mean		3.4	9.7	13.4	15.3	14.1	11.3
			Precipitation (mm)				
1968	442	19	48	89	20	80	237
1969	330	32	16	50	26	42	134
1970	300	5	25	36	23	41	125
1971	551	15	2	176	66	39	283
1972	512	3	1	54	58	46	159
1973	361	5	10	56	16	88	170
1974	478	13	52	13	69	59	193
1975	411	22	21	71	29	56	177
1976	548	8	51	93	65	157	366
1977	551	4	156	52	118	58	384
1978	392	30	23	52	60	79	214
1979	421	33	30	67	80	28	205
1980	569	14	51	67	67	113	298
1981	312	24	61	39	42	29	171
1982	587	5	16	29	171	127	343
1983	520	34	30	136	131	33	330
1984	454	8	59	94	18	35	206
1985	360	4	6	54	15	61	136
1986	468	73	21	19	108	14	162
1987	375	17	46	60	91	69	266
Mean	447	15	36	65	64	65	228

[1] GS=growing season May to August, inclusive.

Appendix 8.2 Continued.

Table 8.2 Potential evapotranspiration and water deficits data for the Beaverlodge metereological site for the years 1968 to 1987.

Year	Apr	May	June	July	Aug	GS[1]
			Evapotranspiration (mm)			
1968	27	87	108	124	86	405
1969	38	101	119	129	101	450
1970	73	86	128	131	112	457
1971	33	111	105	122	111	449
1972	22	112	107	114	112	445
1973	29	107	107	134	100	448
1974	27	70	124	111	95	400
1975	28	91	113	133	84	421
1976	47	96	95	113	75	379
1977	62	80	113	100	84	377
1978	33	87	130	127	97	441
1979	19	75	112	126	108	421
1980	65	94	113	122	85	414
1981	25	105	112	138	141	496
1982	20	89	137	120	65	411
1983	36	90	102	108	110	410
1984	49	80	108	138	111	437
1985	33	116	119	152	99	486
1986	24	89	122	118	125	454
1987	54	104	121	128	81	434
Mean	37	94	115	124	99	432
			Water Deficit (mm)			
1968	8	39	19	104	6	168
1969	6	85	69	103	59	316
1970	68	61	92	108	71	332
1971	18	99	+ 71	56	72	156
1972	19	111	53	56	66	286
1973	24	97	51	118	12	278
1974	14	18	111	42	36	207
1975	6	70	42	99	28	239
1976	39	45	2	48	+ 82	13
1977	58	+ 76	61	+ 18	26	+ 7
1978	3	64	78	67	18	227
1979	+ 14	45	45	46	80	216
1980	51	43	46	55	+ 28	116
1981	1	44	73	96	112	325
1982	15	60	108	+ 51	+ 62	55
1983	2	60	+ 34	+ 23	77	80
1984	41	21	14	120	76	231
1985	29	110	65	137	38	350
1986	+ 49	68	103	10	111	292
1987	37	59	62	37	12	170
Mean	19	56	49	61	36	203

[1] GS=growing season May to August, inclusive.

+ Indicates excess water, greater than evapotranspiration.

Appendix 8.3 Yield data from different cropping systems (1968-1987).

Table 8.3 The annual crop yields for the different cropping systems of the Beaverlodge Long-term Cropping System Experiment.

	Cropping System				
Year	CB[1]	Bf	Fb	CG	CL
			kg ha^{-1}		
1968	2200	2610	-EY[2]	-EY	-EY
1969	2550	2340	11200	7530	9790
1970	2450	2540	4860	3050	3290
1971	900	1260	-EY	2460	4840
1972	2630	3510	1750	1230	1660
1973	830	2060	4910	2420	4910
1974	1640	2520	850U[3]	-EY	-EY
1975	1640	2240	2820	2690	-F[4]
1976	2250	2360	6450	9540	-F
1977	-F	-F	1930U	3810	-F
1978	4670	4520	-EY	-EY	-EY
1979	-L[5]	-L	7800	6450	7210
1980	2330	2290	6070	4140	4050
1981	1440	2570	-EY	5260	6680
1982	2650	3390	6410	6650	5310
1983	960	510	5750	4210	-EY
1984	-F	-F	-EY	3100	5760
1985	2011	2386	2347	2230	1851
1986	1808	2788	6994	6230	3971
1987	2358	2212	5189	4712	3416
Total Yield[6]	35317	42106	75330	75712	62738
Mean[7]	2077	2477	5022	4454	4826

[1] CB -continuous barley, BF -barley/forage, Fb -forage barley
CG -continuous grass and CL -continuous legume

[2] EY-indicates establishment year.

[3] U -indicates underseeded to barley.

[4] F -fallow.

[5] L -samples lost due to fire in drying area.

[6] -Total Yield indicates the harvested portion or biomass over all years.

[7] -Mean is the average for all harvested years.

Appendix 8.3 Continued.

Table 8.4 Relative yield (%) of barley in the barley-forage cropping system (Bf) compared to that in the continuous barley cropping system (CB).

Year	CB	Bf Year after forage 1st	 2nd	 3rd
	kg ha^{-1}	%		
1968	2200	119		
1969	2550		92	
1970	2450			104
1971	900	140		
1972	2630		132	
1973	830			248
1974	1640	154		
1975	1640		137	
1976	2250			105
1977	-F[1]		-F	
1978	4670	97		
1979	-L[2]		-L	
1980	2330			98
1981	1440	178		
1982	2650		128	
1983	960			53
1984	-F		-F	
1985	2011	119		
1986	1808		154	
1987	2358			94
Mean[3]	2077	135	129	91

[1] -see Table 8.3

[2] -F indicates fallow.

[3] -L indicates sample lost due to fire in drying area.

[4] -Mean of all harvest years.

Appendix 8.4 Correlation between cropping system yields and annual meteorological data.

Table 8.5 Pearson simple correlation matrix for selected yield and climatic parameters from the Beaverlodge Long-term Cropping System Experiment.

	Year	CB[1]	Bf	Fb	CG	CL	AP	GSP	GST	GSPE	GSWD
Year	1.000										
CB	0.007	1.000									
Bf	-0.026	0.830**[2]	1.000								
Fb	0.009	0.214	-0.152	1.000							
CG	0.129	0.313	0.111	0.760**	1.000						
CL	-0.231	-0.094	-0.209	0.937**	0.712**	1.000					
AP	0.094	-0.086	-0.114	-0.157	0.118	-0.208	1.000				
GSP	0.187	-0.041	-0.255	0.002	0.326	0.002	0.774**	1.000			
GST	0.469*	0.059	-0.068	0.215	0.023	-0.159	0.124	0.300	1.000		
GSPE	0.144	-0.061	0.100	0.103	-0.348	-0.105	-0.673**	-0.741**	0.319	1.000	
GSWD	0.008	0.285	0.498*	0.259	0.355	0.200	-0.232	-0.305	0.237	0.326	1.000

VARIABLES

Year = 1968 to 1987,inclusive
CB = Continuous barley yield(kg ha^{-1})
Bf = Rotation barley yield(kg ha^{-1})
Fb = Rotation forage yield(kg ha^{-1})
CG = Continuous grass yield(kg ha^{-1})
CL = Continuous legume yield(kg ha^{-1})
AP = Annual precipitation(mm)
GSP = Growing season precipitation (mm)
GST = Growing season mean temperature (°C))
GSPE = Growing season potential evapotranspiration (mm)
GSWD = Growing season water deficit (mm)

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[1]-see Table 8.3

[2]-* significant $P \leq 0.05$, ** significant $P \leq 0.01$

Appendix 8.5 Soil-test data for cropping system soils (1968-1986).

Table 8.6 Mean amounts of soil nitrogen (NO_3-N) for the years 1976 to 1986 for the Beaverlodge Long-term Cropping System Field Experiment.

					Year						
Depth cm	1968	1976	1977	1978	1979	1980	1982	1983	1984	1986	Mean
					$\mu g\ g^{-1}$						
					CB[1] Cropping System						
0-15	1.3	10.7	24.7	9.0	3.9	6.7	3.0	1.0	37.7	40.2	13.8
15-30	0.3	1.7	6.7	5.6	3.4	1.7	1.0	0.0	24.2	18.2	6.3
30-60		1.1	1.7	1.7	1.7	1.1	1.0	0.5	6.9		2.0
60-90			1.1	1.1	1.7	1.7	1.0	0.5	3.2		1.5
					Bf Cropping System						
0-15	1.0	10.7	14.0	12.3	1.7	10.1	1.0	0.8	43.0	34.2	12.9
15-30	1.0	1.1	3.4	11.2	0.6	3.4	0.0	0.0	29.5	16.2	6.6
30-60		0.6	1.1	1.7	0.6	1.7	0.0	0.0	7.4		1.6
60-90			1.1	1.7	1.1	1.7	0.0	0.0	3.2		1.3
					Fb Cropping System						
0-15	1.0	7.9	37.0	14.6	2.8	0.6	3.0	0.3	34.5	1.5	10.3
15-30	0.3	0.6	9.5	33.1	5.0	0.6	1.0	0.0	8.2	1.3	6.0
30-60		0.6	1.7	3.4	1.1	1.1	0.0	0.0	1.9		1.2
60-90			1.1	1.7	1.7	1.1	0.0	0.0	2.0		1.1
					CG Cropping System						
0-15	0.3	0.6	12.3	56.0	0.6	2.3	2.0	0.0	0.8	6.3	8.1
15-30	0.0	0.0	2.3	30.3	0.6	0.6	0.0	0.0	0.0	1.7	3.6
30-60		C.0	0.6	5.1	0.6	0.6	2.0	0.0	0.3		1.2
60-90			0.6	2.3	1.1	1.1	0.0	0.0	0.8		0.8
					CL Cropping System						
0-15	1.0	15.7	31.4	1.8	1.1	3.8	4.0	0.8	2.7	2.2	9.2
15-30	0.8	11.2	15.7	14.6	1.7	1.1	1.0	0.0	1.0	1.0	4.8
30-60		8.4	9.5	6.7	1.7	1.1	0.0	0.0	0.5		3.5
60-90			2.8	5.6	2.3	1.1	0.0	0.0	1.0		1.8

[1] see Table 8.3

Samples were usually obtained in the fall of the year and 4 cores were bulked for each of the four cropping system replicates.

Appendix 8.5 Continued.

Table 8.7 Mean amounts of available P for the years 1976 to 1986 for the Beaverlodge Long-term Cropping System Field Experiment.

Depth cm	Year 1968	1976	1977	1978	1979	1980 µg g⁻¹	1982	1983	1984	1986	Mean
					CB[1] Cropping System						
0-15	13.0	21.3	19.1	18.5	20.7	16.3	16.0	16.0	17.7	19.7	17.8
15-30	1.5	0.6	0.6	0.6	1.1	1.1	0.0	0.0	1.7	1.3	0.9
30-60		0.0	0.6	0.6	0.6	0.6	0.0	0.0	0.5		0.4
60-90			0.6	0.0	0.6	0.6	0.0	0.0	0.8		0.4
					Bf Cropping System						
0-15	15.5	21.3	14.6	12.3	16.8	15.1	24.0	11.7	20.2	18.5	17.0
15-30	1.5	0.6	0.6	0.6	0.6	1.7	0.0	0.3	5.2	1.7	1.3
30-60		0.6	0.6	0.6	0.6	1.1	0.0	2.2	0.6		0.8
60-90			0.6	0.0	0.0	0.6	0.0	0.0	0.0		0.2
					Fb Cropping System						
0-15	21.0	10.7	10.7	8.4	11.8	17.9	13.0	11.7	14.7	12.0	13.2
15-30	2.0	0.6	0.6	0.6	1.7	2.3	0.0	0.0	5.0	7.0	2.0
30-60		0.0	0.6	0.6	1.1	1.7	0.0	0.0	0.4		0.6
60-90			0.6	0.0	0.6	0.6	0.0	0.0	0.3		0.3
					CG Cropping System						
0-15	18.0	11.8	9.0	10.7	15.7	20.7	11.0	6.0	5.7	10.7	11.9
15-30	2.0	0.6	0.6	1.1	1.1	2.8	0.0	0.8	1.7	1.3	1.2
30-60		0.6	0.6	0.6	1.1	1.1	0.0	0.0	0.1		0.5
60-90			0.6	0.6	0.6	0.6	0.0	0.0	0.3		0.4
					CL Cropping System						
0-15	20.5	26.9	26.3	25.8	29.1	37.5	23.0	21.7	23.2	26.7	26.1
15-30	2.8	2.3	0.6	1.1	2.3	4.5	0.0	1.0	6.5	2.0	2.3
30-60		0.6	1.1	0.6	1.1	2.3	0.0	0.0	0.8		0.8
60-90			0.6	0.0	0.6	0.6	0.0	0.0	0.3		0.3

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[1] see Table 8.3

Samples were usually obtained in the fall of the year and 4 cores were bulked from each of the four cropping system replicates.

Appendix 8.5 Continued.

Table 8.8 Mean available K for the years 1976 to 1986 for the Beaverlodge Long-term Cropping System Field Experiment.

					Year						
Depth cm	1968	1976	1977	1978	1979 µg g^{-1}	1980	1982	1983	1984	1986	Mean
					CB[1] Cropping System						
0-15	251	151	300	305	195	321	227	260	239	212	246
15-30	211	181	257	340	178	335	164	228	231	174	230
30-60		144	221	247	153	293	157	153	192		195
60-90			162	182	134	206	137	131	135		155
					Bf Cropping System						
0-15	254	301	253	232	239	269	210	217	218	190	238
15-30	222	190	263	285	202	270	220	210	225	167	225
30-60		151	170	232	170	256	157	176	188		188
60-90			104	147	125	191	111	148	121		135
					Fb Cropping System						
0-15	286	270	304	243	212	281	174	187	224	168	235
15-30	205	170	225	249	222	266	204	177	227	172	212
30-60		148	175	215	188	298	144	149	196		189
60-90			131	151	154	254	152	124	153		160
					CG Cropping System						
0-15	240	319	270	254	220	315	182	236	198	181	242
15-30	194	224	229	328	239	258	199	197	166	163	220
30-60		162	179	212	176	307	167	178	286		208
60-90			124	165	145	227	120	122	173		153
					CL Cropping System						
0-15	275	280	318	319	241	337	195	211	216	188	258
15-30	198	160	167	253	158	290	177	178	163	168	191
30-60		158	196	202	175	293	153	173	169		190
60-90			142	174	140	226	113	128	173		157

[1] see Table 8.3

Samples were usually obtained in the fall of the year and 4 cores were bulked from each of the four cropping system replicates.

Appendix 8.6 Cropping system soil profile chemical data.

Table 8.9 Average total C, carbonate C, organic C, nitrogen, organic C to nitrogen and phosphorus for each treatment and depth intervals.

Cropping System	Depth cm	Total-C %	CO_3-C. %	OM-C[1] %	N %	C:N[2] ratio	P %
CB[3]	0-15	2.93	0.13	2.80	0.25	11.16	0.060
	15-30	1.00	0.15	0.85	0.11	7.73	0.030
	30-45	1.00	0.22	0.78	0.10	7.58	0.039
	45-60	1.16	0.39	0.77	0.09	9.11	0.050
	60-90	1.30	0.48	0.82	0.07	11.23	0.048
	90+	1.31	0.55	0.77	0.06	12.48	0.048
	mean	1.45b[4]	0.32c	1.13ab	0.11a	9.88b	0.046a
Bf	0-15	3.30	0.15	3.15	0.27	11.73	0.057
	15-30	1.15	0.13	1.02	0.11	8.80	0.031
	30-45	0.93	0.21	0.74	0.10	7.58	0.035
	45-60	1.23	0.66	0.57	0.08	7.05	0.048
	60-90	1.73	0.91	0.81	0.07	12.20	0.050
	90+	1.54	0.83	0.72	0.06	13.00	0.044
	mean	1.65a	0.48a	1.17ab	0.12a	10.06b	0.044a
Fb	0-15	2.87	0.14	2.74	0.25	11.07	0.054
	15-30	1.20	0.14	1.07	0.12	8.71	0.029
	30-45	0.98	0.21	0.77	0.10	7.92	0.033
	45-60	1.21	0.52	0.69	0.08	8.77	0.043
	60-90	1.51	0.79	0.72	0.07	10.32	0.049
	90+	1.50	0.81	0.70	0.05	13.29	0.044
	mean	1.54ab	0.43ab	1.11b	0.11a	10.01b	0.042a
CG	0-15	3.72	0.15	3.57	0.30	11.80	0.054
	15-30	1.07	0.15	0.92	0.11	8.31	0.028
	30-45	0.87	0.17	0.70	0.10	7.32	0.033
	45-60	1.12	0.39	0.73	0.09	8.55	0.049
	60-90	1.49	0.71	0.78	0.07	11.68	0.052
	90+	1.61	0.79	0.83	0.06	13.21	0.054
	mean	1.64a	0.39abc	1.25a	0.12a	10.14b	0.045a
CL	0-15	3.51	0.14	3.37	0.25	14.94	0.069
	15-30	0.91	0.11	0.80	0.10	8.01	0.032
	30-45	0.98	0.17	0.81	0.10	8.28	0.034
	45-60	1.26	0.40	0.86	0.09	9.81	0.050
	60-90	1.37	0.60	0.77	0.06	12.95	0.044
	90+	1.51	0.61	0.90	0.06	15.04	0.047
	mean	1.59ab	0.34bc	1.25a	0.11a	11.51a	0.046a

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[1] organic matter carbon = total carbon - carbonate carbon

[2] C:N=organic matter carbon : total nitrogen

[3] see Table 8.3

[4] Duncan multiple range test, cropping system means in columns with same letter are not significantly different ($P \leq 0.05$)

Appendix 8.6 Continued.

Table 8.10 Some selected chemical characteristics for each of the cropping system soil profiles.

	pH		Exchangeable Cations[1]				Total	Total	BS
	H_2O	$CaCl_2$	Ca	Mg	K	Na	Bases	CEC	%
			c mol(+) kg^{-1}						
				CB[2] Cropping System					
0-15	6.3	5.6	12.6	3.5	0.62	0.24	17.0	26.0	65.9
15-30	6.1	5.4	14.2	8.3	0.61	0.81	24.0	34.2	69.6
30-45	6.6	6.3	19.4	10.1	0.52	1.44	31.4	37.7	86.7
45-60	6.8	7.0	27.3	8.8	0.42	1.71	38.2	32.5	117.6
60-90	7.6	7.6	55.7	8.4	0.37	1.75	66.2	27.3	241.3
90+	7.8	7.5	62.6	8.2	0.35	1.63	72.8	26.3	277.9
				Bf Cropping System					
0-15	6.2	5.8	14.3	3.7	0.66	0.50	19.1	28.0	70.2
15-30	6.2	5.5	13.5	5.9	0.55	0.48	20.4	30.2	70.0
30-45	6.6	6.0	22.4	10.8	0.49	0.95	34.7	38.3	92.9
45-60	7.3	7.2	33.8	8.2	0.40	1.23	43.7	32.4	141.2
60-90	7.9	7.6	45.3	6.3	0.27	1.13	53.0	27.2	195.6
90+	8.0	7.6	46.9	7.0	0.31	1.11	55.3	25.3	218.6
				Fb Cropping System					
0-15	6.2	5.5	13.0	4.1	0.52	0.36	17.9	28.3	64.1
15-30	6.0	5.2	14.1	8.5	0.49	0.88	24.0	34.4	68.5
30-45	6.3	5.9	16.2	8.8	0.42	1.41	26.8	37.5	71.7
45-60	7.1	6.8	30.9	8.2	0.35	1.78	41.3	31.9	131.6
60-90	7.5	7.4	67.5	7.6	0.30	1.89	77.3	27.4	289.1
90+	7.8	7.5	44.1	6.6	0.26	1.56	52.5	24.1	217.3
				CG Cropping System					
0-15	5.9	5.3	14.8	3.4	0.62	0.23	19.0	29.7	62.5
15-30	6.1	5.3	14.6	8.0	0.54	0.49	23.7	32.5	73.5
30-45	6.2	5.7	16.9	9.2	0.52	0.70	27.4	37.4	73.6
45-60	7.1	6.9	35.7	10.1	0.43	0.90	47.2	32.5	142.5
60-90	7.7	7.6	51.7	6.6	0.31	0.74	59.4	26.3	232.2
90+	7.8	7.5	63.5	7.7	0.30	1.28	72.8	25.0	303.6
				CL Cropping System					
0-15	6.0	5.5	13.8	3.1	0.65	0.12	17.7	27.2	65.3
15-30	5.8	5.2	10.4	5.1	0.42	0.43	16.3	25.5	63.9
30-45	6.0	5.6	18.0	9.3	0.49	0.98	28.8	36.1	81.7
45-60	7.4	7.1	32.6	8.7	0.39	1.09	42.8	32.0	141.1
60-90	7.9	7.6	37.5	7.9	0.34	1.16	46.9	27.8	167.9
90+	8.1	7.6	35.3	7.3	0.28	1.03	43.9	27.6	162.5

[1] -Extracted in 1 N NH_4Ac at pH 7(includes soluble cations in lower horizons).

[2] -see Table 8.3

Appendix 8.7 Selected chemical data for cropping system soils

Table 8.11 The surface horizon(0-15 cm) bulk densities for each of the five cropping systems.

	Cropping Systems					
Method	CB[1]	Bf	Fb	CG	CL	Mean
			Mg m^{-3}			
loose	1.05	1.04	1.02	0.94	0.97	1.00A[2]
packed	1.12	1.13	1.07	1.00	1.06	1.08 B
Mean	1.08 c	1.09 c	1.04 b	0.97a	1.02 b	

[1] see Table 8.3

[2] Means followed by same letters are not significantly different($P \leq 0.05$) from each other. Capital letters within columns lowercase letters within rows.

Table 8.12 The comparison of the surface horizon modulus of rupture in normal and puddled condition.

	Cropping System					
Soil Condition	CB[1]	Bf	Fb	CG	CL	Mean
			kPa			
normal	64 c[2]	39 b	41 b	31a	34 b	42A
puddled	1020 c	615a	1172 c	913 b	593 a	863 B

[1] see Table 8.3

[2] Means followed by different letters are significanly different, capital letters for mean column and lowercase letters for rows of normal and puddled soil.

Appendix 8.7 Continued.

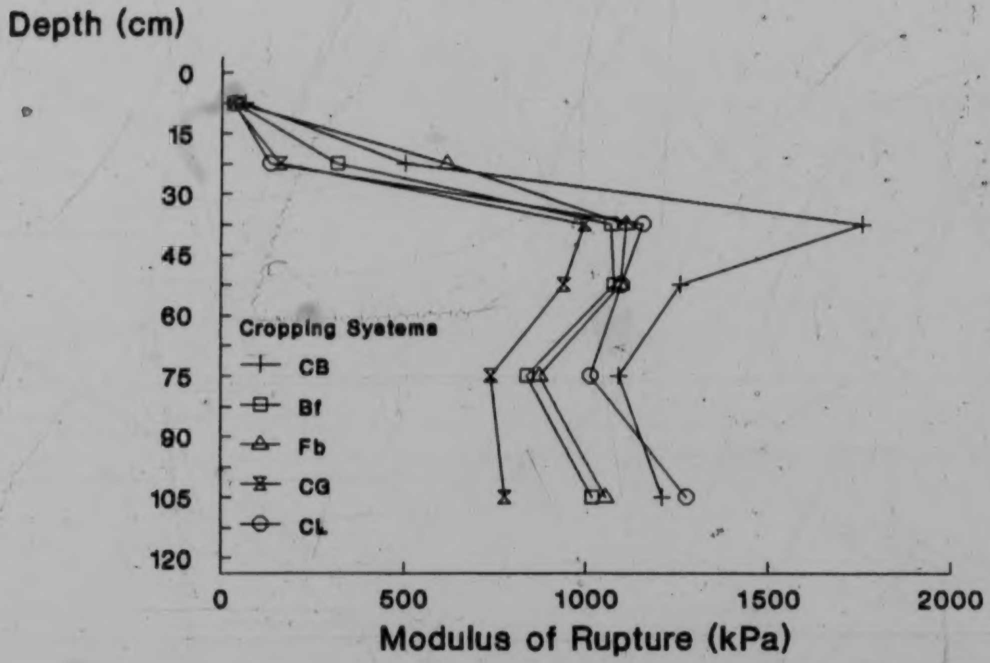

Figure 8.2 Modulus of rupture (kPa) for each of the five cropping system soils at six depth intervals.

Appendix 8.8 Root data for the different cropping systems.

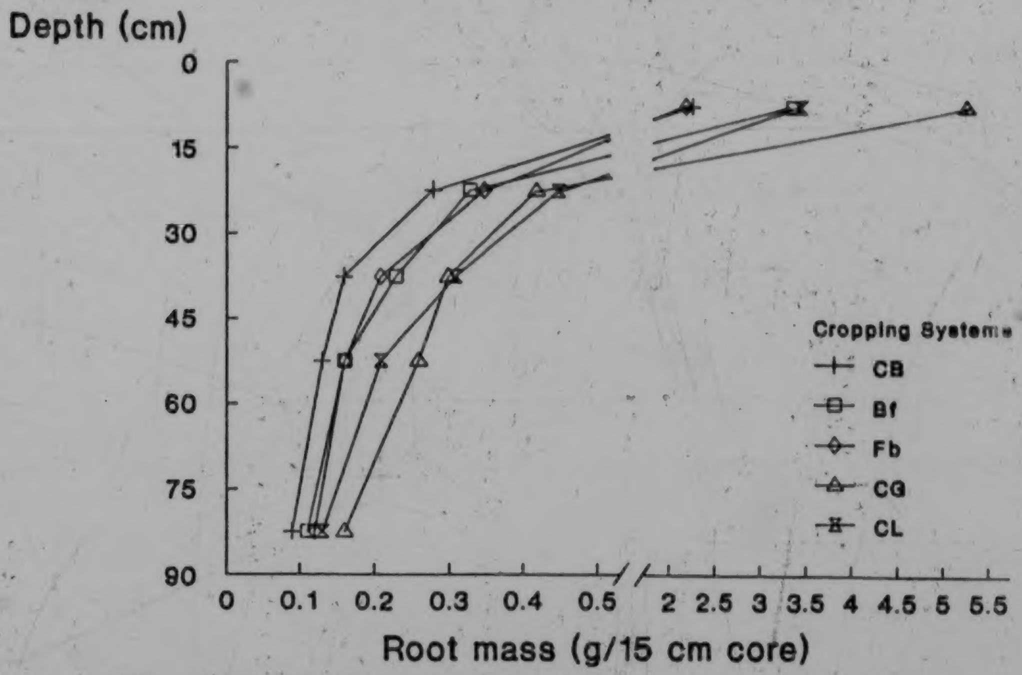

Figure 8.3 Root mass (g per 15 cm core) in soils from each cropping system at five depth intervals.

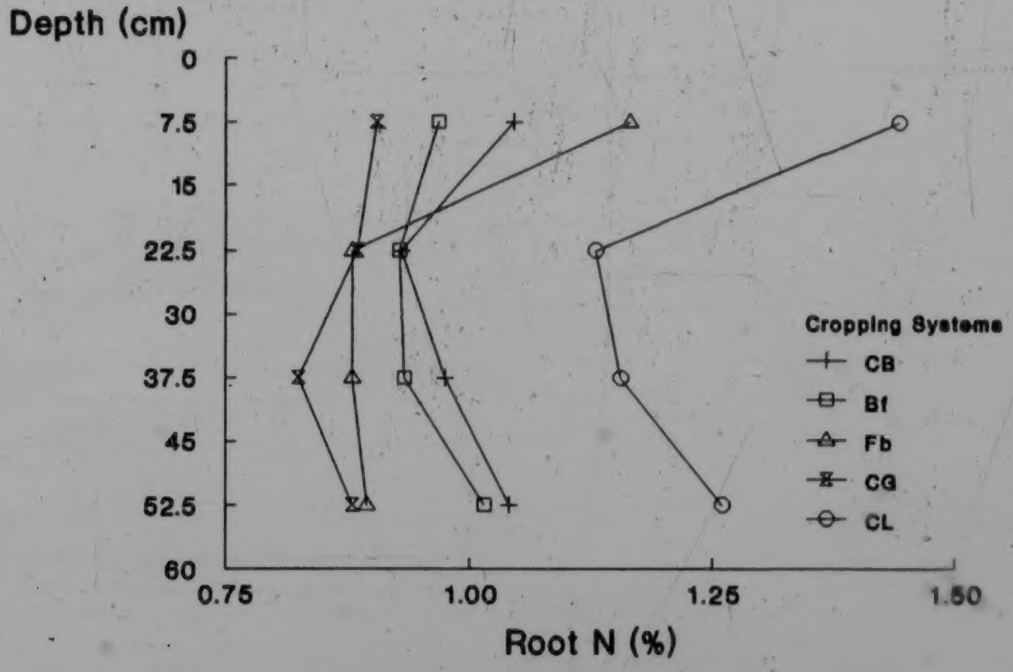

Figure 8.4 The N content (%) of the root material from the five cropping systems at four depth intervals.

Appendix 8.9 Determining aggregate stability by dispersion and slaking.

A NEW METHOD OF AGGREGATE STABILITY MEASUREMENT

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8.9.1 Introduction

As the name suggests, it measures two aspects of soil structure, dispersion and slaking.

Dispersion: this is the tendency of soil particles to separate into colloidal size materials when mechanically agitated in suspension. Soils which are highly dispersive show a tendency to crust and clog finer pores impeding drainage. Soils naturally high in clay where clay particles are not strongly orientated, or bound with organic matter or strongly bound by ionic interactions would be susceptible to dispersion.

Slaking: this is the tendency of aggregates to fracture along lines of weakness. This measure should be independent of the microaggregates status of the soil, as large scale disintergration only is being considered.

Slaking correlates with disruption caused by explosive release of entrapped air in soil pores which occurs when dry soil is rapidly rewetted. Use of field moist substantiously reduces this phenomenon. Slaking acts upon major linkage points within the soil aggregate, by reducing cohesion and cementing bonds, also at this scale particle-particle friction and physical intermeshing by organic material are increasingly important stabilizing factors.

In the dispersion part of the test, the soil suspension is observed after 15 seconds settling. In this time all material greater than 0.05 mm diameter has fallen 3.5 cm, the average depth of the soil suspension. Pores which drain at 5 Pa are 0.06 mm diameter or greater the dispersion index looks at particles finer than those which clog large soil pores. The small particles may form surface crusts after puddling. The slaking index deals with coarser fragments than the dispersion index and, therefore, indicates how susceptible the soil is to clogging of large pores.

8.9.2 How it Works

Equipment required:

1 6 mm sieve
1 3 mm sieve
1 pair tweezers or forceps
8 boiling tubes and corks
1 scalpel or sharp knife
1 measuring cylinder
1 bright light (e.g. an adjustable desk lamp)

To speed up the operation it is preferable to have 2 or 3 batches of samples running at the same time, hence several test-tube racks are desirable extras.

Field sampling: Once the area to be sampled has been selected a 10 m x 10 m grid is paced out and pairs of random numbers from 1-10 are used to locate 3 sampling points within the sampling grid.

Sample proportion: A sample of field moist topsoil is gently sieved through 6 mm and 3 mm sieves. If soil aggregates are marked by roots or form clods due to cultivation, gentle prising apart may be carried out before sieving. The proportion less than 6 mm and greater than 3 mm is taken from on top of the 3 mm sieve.

Using a pair of tweezers or forceps, 3 aggregates are selected from the 6-3 mm pile and are placed in a 2.5 cm x 15 cm boiling tube.

These aggregates are crushed and fully dispersed in 40 ml of water. Making a slurry with a rubber policeman and gradually adding water is generally the best way to achieve dispersion. Some soils with strong microaggregation, e.g. allophanic soils, will not disperse readily even after this treatment.

A further 3 aggregates are selected and are sliced in half using a scalpel. These 6 fragments are placed in another boiling tube.

Finally, sets of 6 aggregates are placed in more tubes with 10 ml of water being added to each tube and the tubes then corked. A period of at least 10 minutes should be allowed for water to penetrate the aggregates.

Test procedure (Figure 8.5): A sample tube is held in the hand and rapidly inverted at approximately one inversion per second; after a number of inversions which is judged by the experimenter, the standard tube is vigorously shaken, 15 seconds is allowed to pass, at the end of which both tubes are held up to a powerful light, and compared. Direct in line transmission through the light beam is the best configuration to observe the turbidity of the suspensions, due to the high concentrations involved. A direct comparison is made between the standard suspension and the test sample. Inversions are continued until the turbidity of the supsensions are identical. At this point the number of inversions are recorded as the dispersion index.

Concurrently the size of remaining aggregates in the test suspension are compared with the standard divided aggregates. When all the test aggregates are no longer than the divided aggregates the number of inversions up to that point are recorded as the slaking index. In almost all cases the slaking index is greater than the dispersion idex so the two tests can be run concurrently on each replicate.

The tests are run on all six replicates and the mean and standard deviation of the results are recorded.

Time required: This depends on the nature of the soils being sampled. On average an hour should be set aside for each soil, that is analysing 3 sites with 6 replications.

8.9.3 References

McQueen, David. 1982. A new method of aggregate stability measurement. Personal communication, 7 pp, Soil Bureau, DSIR, Lower Hutt, New Zealand.

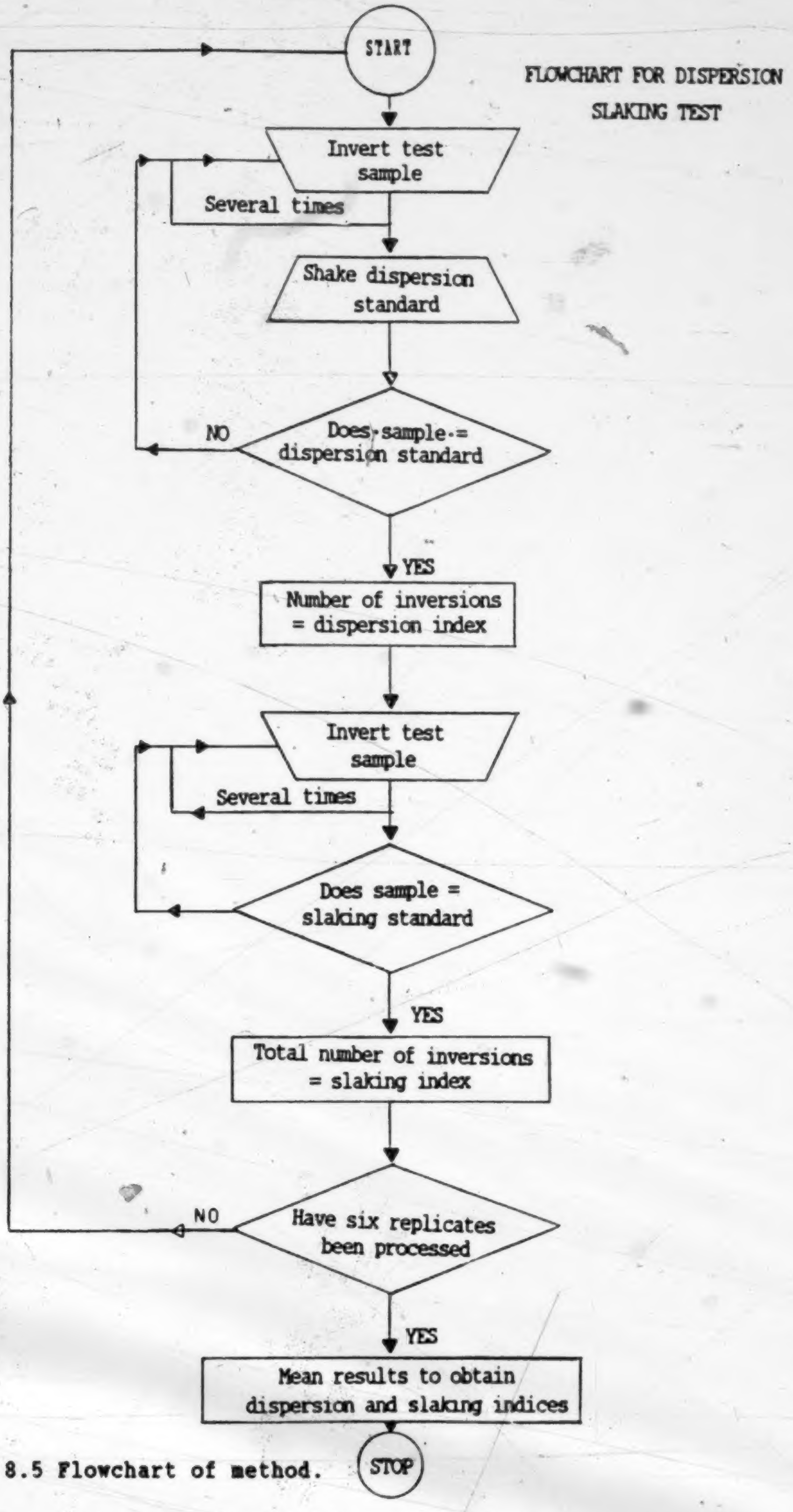
START
FLOWCHART FOR DISPERSION SLAKING TEST
Invert test sample
Several times
Shake dispersion standard
NO
Does sample = dispersion standard
YES
Number of inversions = dispersion index
Invert test sample
Several times
Does sample = slaking standard
YES
Total number of inversions = slaking index
NO
Have six replicates been processed
YES
Mean results to obtain dispersion and slaking indices
STOP

Figure 8.5 Flowchart of method.